Searches for New Physics with BABAR

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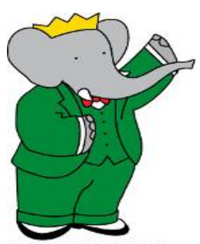

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INSTITUTE OF PARTICLE PHYSICS

McGill

Outline

Tree level processes:

- $B \to D^{(*)} \tau \nu$
- $B^+ \to \tau^+ \nu$ and

FCNC processes:

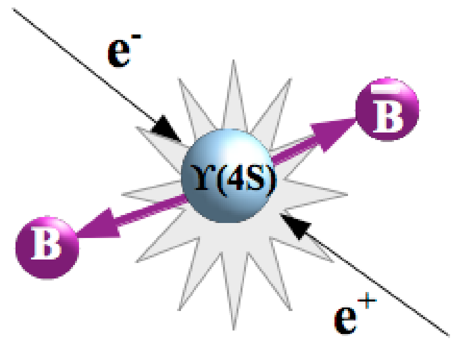
- $b \to s \gamma$
- $B \to K^{(*)} l^+ l^-$

Rare & forbidden decays:

- $B^+ \to h^+ \tau^+ l^-$
- $B^+ \to h^- l^+ l^+$

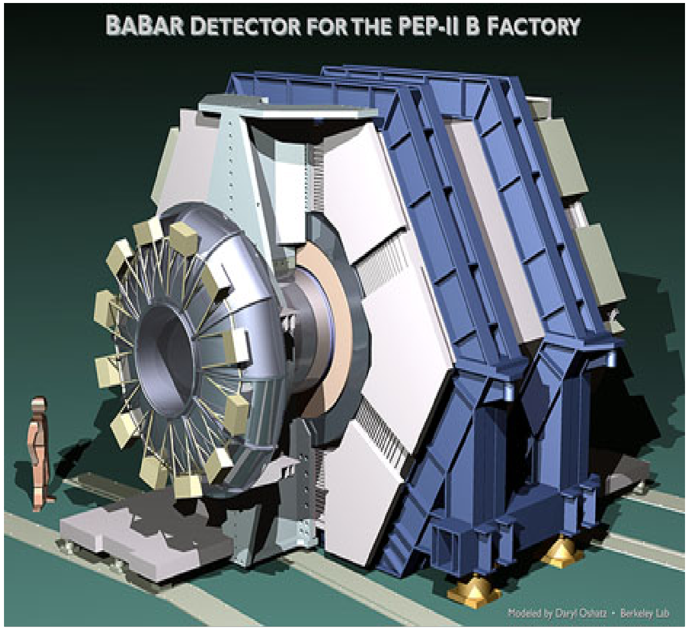
$(h = K, \pi)$

- $B^0 \to \nu \bar{\nu} (\gamma)$ (i.e. invisible final states)



BABAR
data sample of ~470 million $\Upsilon(4S) \to B\bar{B}$ events

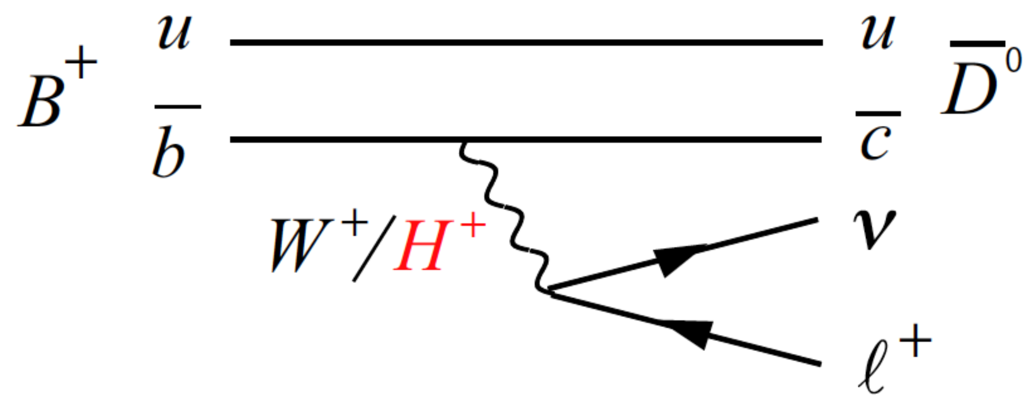
e^+e^- collisions at CM energy of ~10.5 GeV



Tree-level processes

$B \to D^{(*)}\tau\nu$

- Tree-level semileptonic decays sensitive to CKM matrix element $|V_{cb}|$ but heavy 3rd generation lepton provides potential sensitivity to charged Higgs boson



- Dependence on $|V_{cb}|$ and form factors can be (mostly) cancelled in ratio of τ and (e,μ) modes:

$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

SM expectation:

Nierste, Trine, Westhoff (2008) Phys. Rev. **D78** 015066

$$R(D) = 0.31 \pm 0.02$$
$$R(D^*) = 0.25 \pm 0.02$$

- Relatively high branching fractions; experimental challenge is to distinguish between leptonic final states with one or more neutrinos

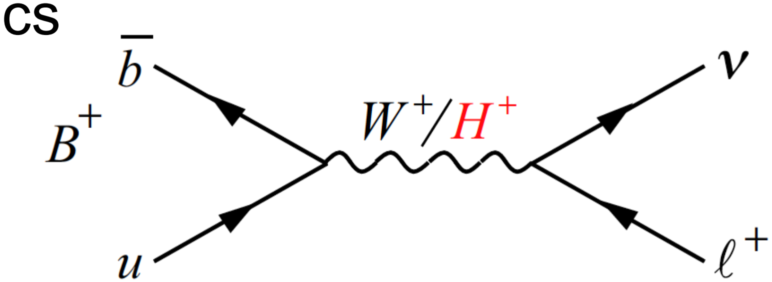
$B^+ \to \tau^+ \nu$

Leptonic B decays, $B^+ \to l^+ \nu$:

$$\mathcal{B}(B^+ \to \ell^+ \nu)_{\rm SM} = \frac{G_F^2 M_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{M_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

– “Parametric” uncertainty in SM prediction from $f_B|V_{ub}|$ problematic due to tension between “inclusive” and “exclusive” $|V_{ub}|$ measurements

- Potentially sensitive to same new physics as semileptonic $B \to D^{(*)} \tau\nu$ decays:



SM branching fractions suppressed by m_l^2 but relative H^+ contribution (2HDM type-II) is independent of lepton type:

$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}(B^+ \to \tau^+ \nu)_{\rm SM} \times r_H$$

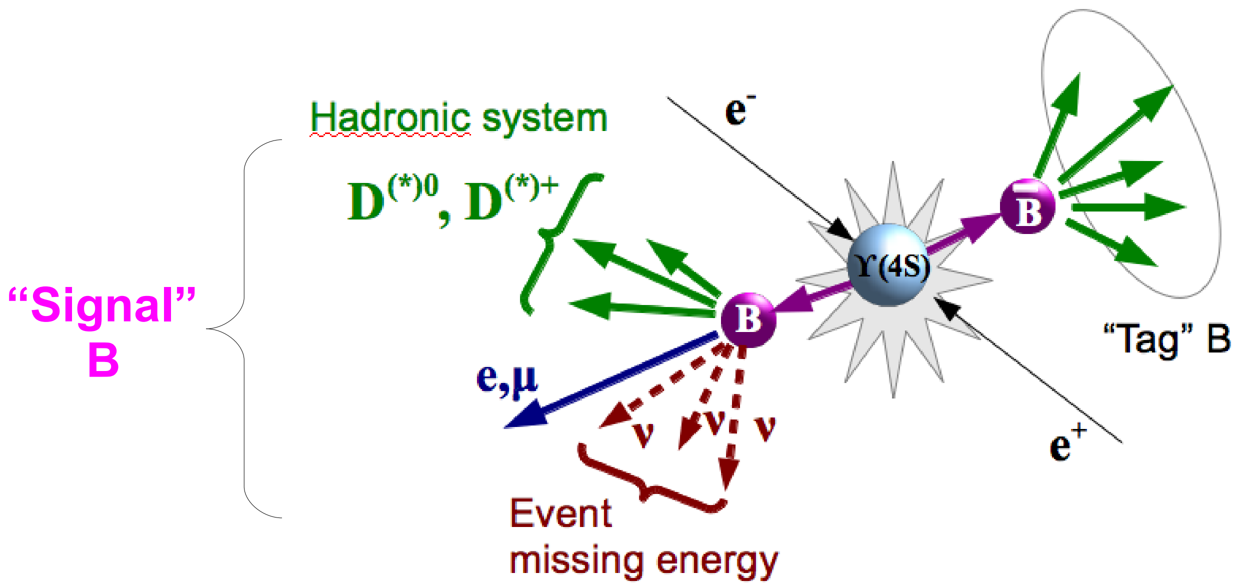
$$r_H = (1 - M_B^2 \tan^2\beta / M_{H^\pm}^2)^2$$

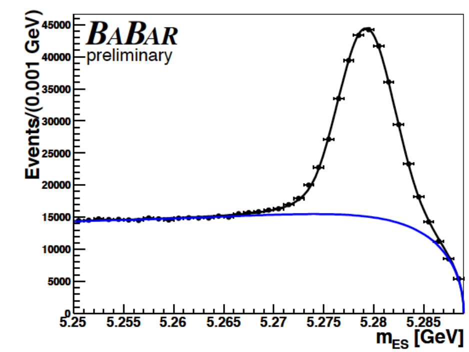
- $B^+ \to \tau^+ \nu$ has largest branching fraction but is experimentally more difficult than $B^+ \to (e,\mu)^+ \nu$ due to additional neutrinos

Methodology

Limited kinematic information available in B decays with neutrinos (or other missing energy) necessitates use of exclusive tag B reconstruction

- Exclusively reconstruct one of the B meson decays ("tag B") in one of several thousand hadronic decay modes:





$$m_{ES} \equiv \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$$
$$\Delta E^* \equiv E^*_B - E^*_{\rm beam}$$

- Improves knowledge of signal kinematics and missing energy, as well as strongly suppressing combinatorial backgrounds

⇒ Similar "tag" methods used for $B \to D^{(*)}\tau\nu$ and $B^+ \to \tau^+\nu$ measurements, as well as searches for rare decays with missing energy signatures

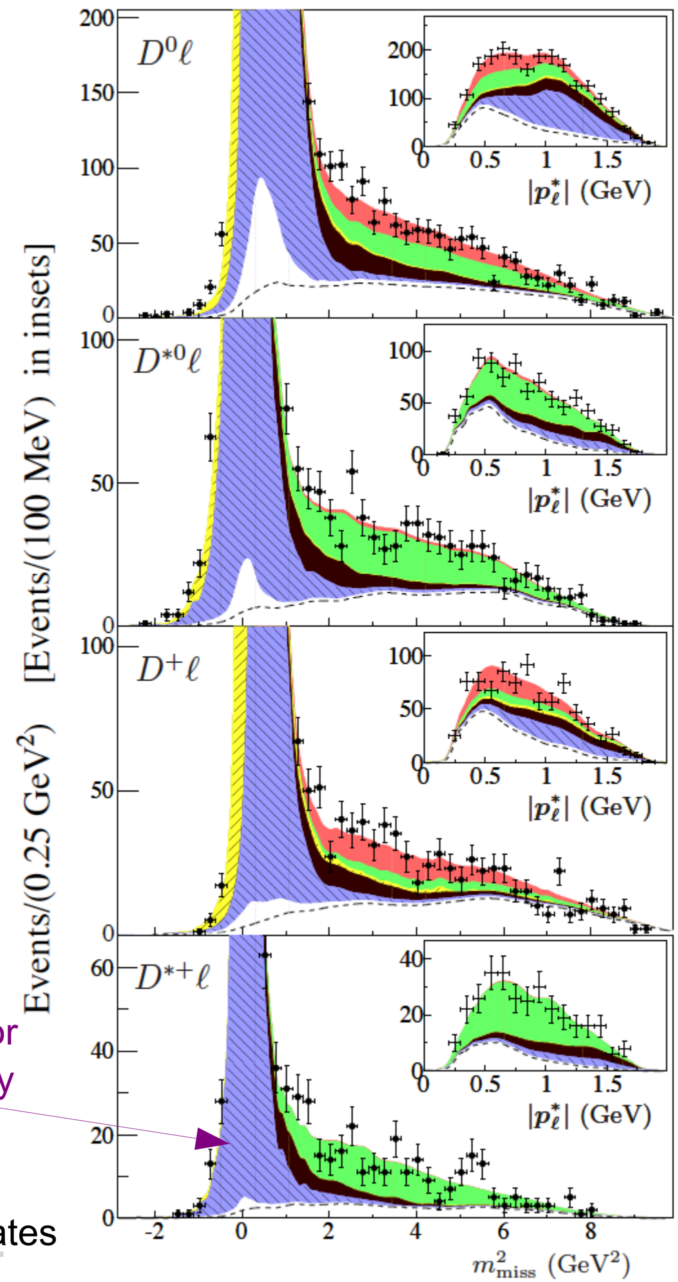
$B \to D^{(*)}\tau\nu$ signal extraction

Measure $B \to D^{(*)}l\nu$ and $B \to D^{(*)}\tau\nu$ simultaneously to determine ratios $R(D^{(*)})$

- 2-d fit to missing mass squared m^2_{miss} and lepton momentum $|\mathbf{p}^*_l|$
- Simultaneous fit to $B \to D^{**}l\nu$ control samples to determine backgrounds*

Decay	N_{sig}	# σ	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)
$B^- \to D^0\tau^-\overline{\nu}_\tau$	314 ± 60	4.7	$0.99 \pm 0.19 \pm 0.13$
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	9.4	$1.71 \pm 0.17 \pm 0.13$
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	177 ± 31	5.2	$1.01 \pm 0.18 \pm 0.12$
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	10.4	$1.74 \pm 0.19 \pm 0.12$
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	6.8	$1.02 \pm 0.13 \pm 0.10$
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	13.2	$1.76 \pm 0.13 \pm 0.11$

First observation of $B \to D\tau\nu$



m^2_{miss} peaks at 0 for Events with exactly one missing ν

$\overline{B} \to D\tau^-\overline{\nu}_\tau$ | $\overline{B} \to D\ell^-\overline{\nu}_\ell$ | $\overline{B} \to D^{**}(\ell^-/\tau^-)\overline{\nu}$
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$ | $\overline{B} \to D^*\ell^-\overline{\nu}_\ell$ | Background

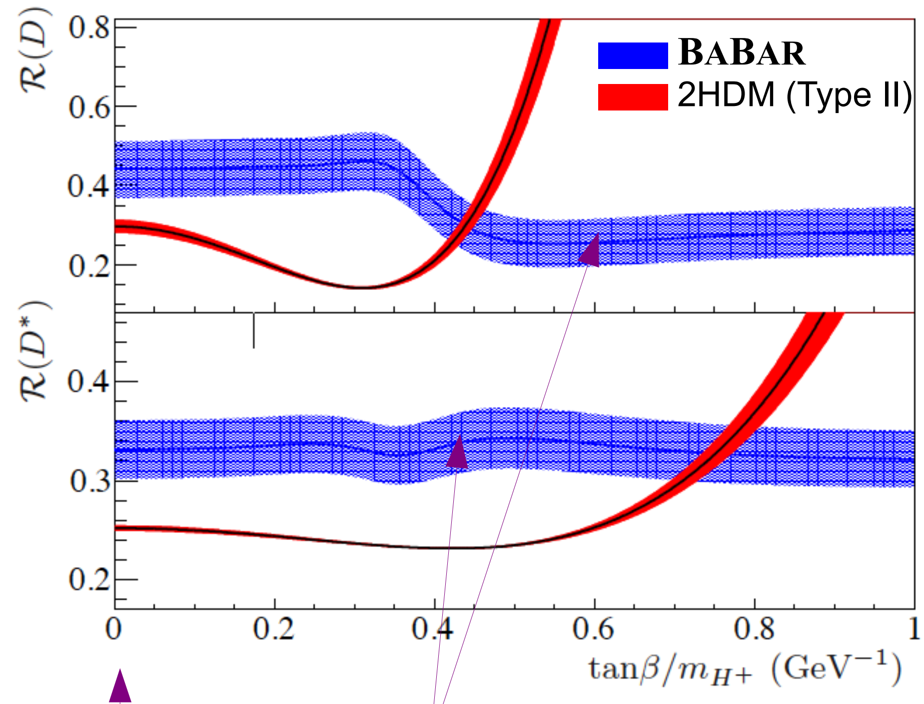
* D** : L=1 charm states

$B \to D^{(*)} \tau \nu$ results

BABAR
arXiv:1205.5442

Branching fraction measurements for $B \to D\tau\nu$ and $B \to D^{(*)}\tau\nu$ exceed SM expectation by 2.0σ and 2.7σ respectively

- -0.27 correlation between modes, yielding combined excess of 3.4σ (p-value 6.9×10^{-4})



"SM"

H^+ contribution modifies experimental pdf shapes and hence signal efficiency as function of $\tan\beta/m_{H+}$

Good consistency between charged and neutral modes

Decay	$\mathcal{R}(D^{(*)})$
$B^- \to D^0\tau^-\overline{\nu}_\tau$	$0.429 \pm 0.082 \pm 0.052$
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	$0.322 \pm 0.032 \pm 0.022$
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	$0.469 \pm 0.084 \pm 0.053$
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	$0.355 \pm 0.039 \pm 0.021$
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	$0.440 \pm 0.058 \pm 0.042$
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	$0.332 \pm 0.024 \pm 0.018$

Isospin constrained

- Interpretation of R(D) and R(D*) within 2HDM (type II) yields inconsistent results

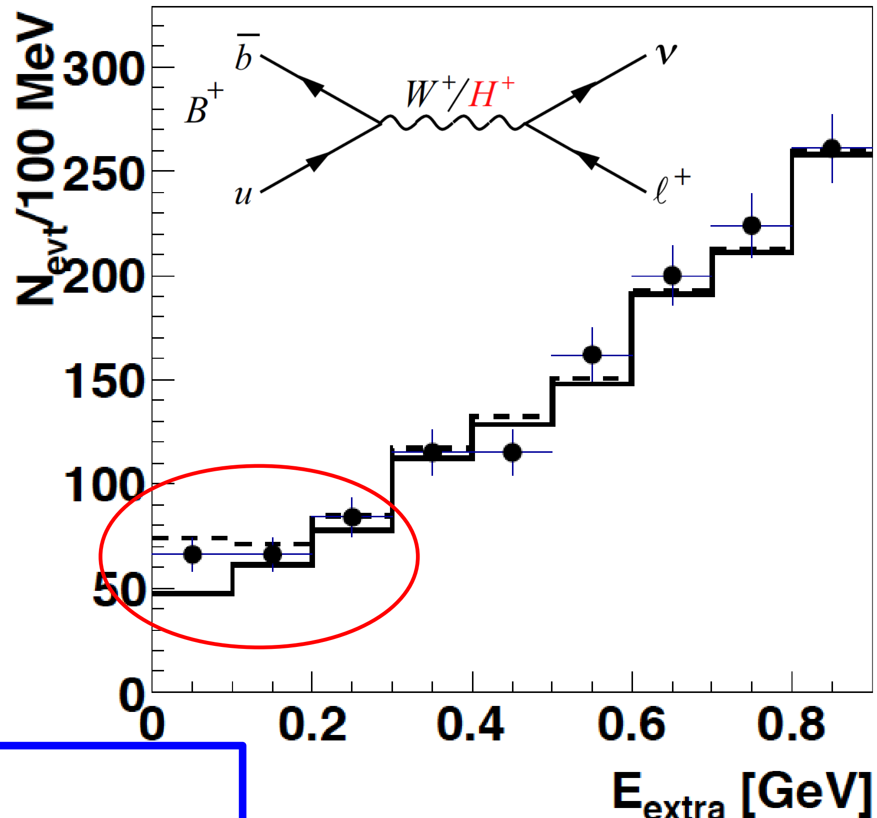
$B^+ \to \tau^+ \nu$

BABAR Preliminary

New BABAR measurement based on hadronic tag reconstruction method

- Consider 1-prong τ decay modes (e, μ, π, ρ)
- Require minimal additional activity in detector (E_{extra} ~0)

Excess of events (3.8σ) over background expectation:



$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.83^{+0.53}_{-0.49}(\text{stat.}) \pm 0.24(\text{syst.})) \times 10^{-4}$$

$(1.79 \pm 0.48) \times 10^{-4}$ ⇐ combination with (statistically independent) *BABAR* semileptonic-tag analysis

B. Aubert et al., Phys. Rev. D 81, 051101(R) (2010)

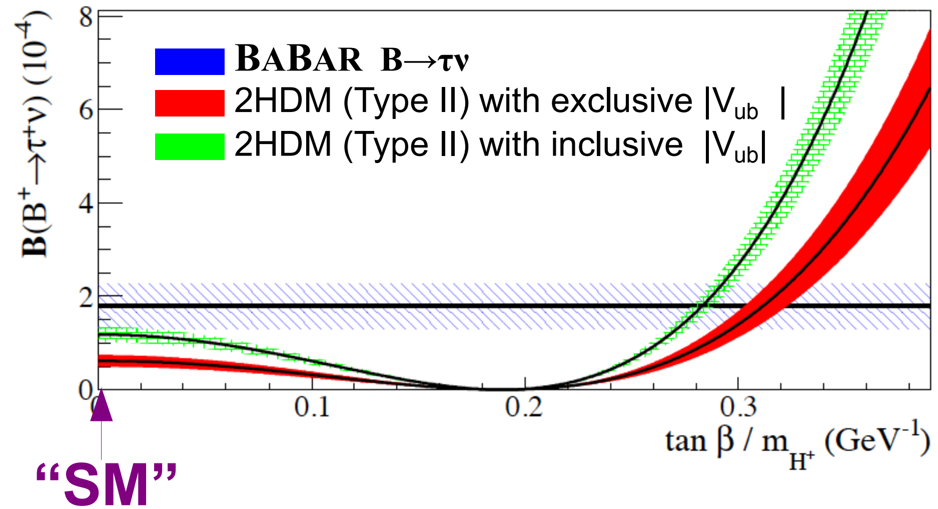
- Consistent with previously published BABAR and Belle analyses based on independent data samples

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

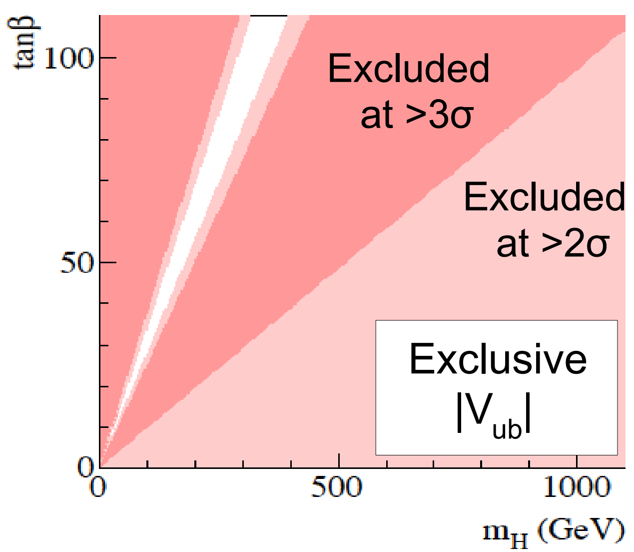
BABAR Preliminary

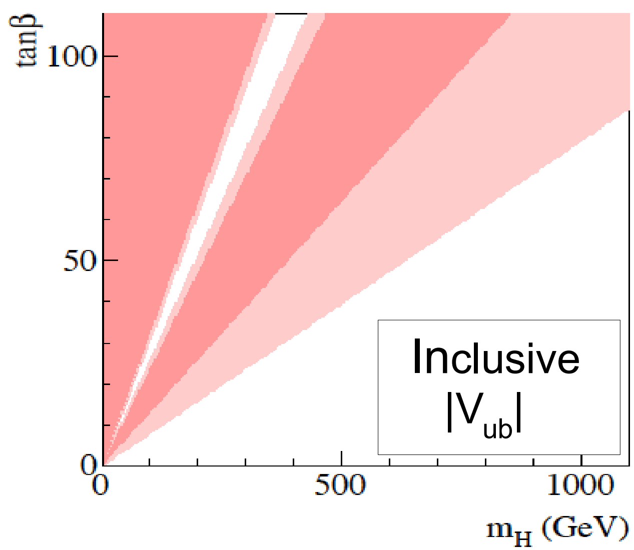
SM branching fraction prediction depends on $f_B |V_{ub}|$ hence large uncertainty (ambiguity?) in comparison with experimental results:

- $|V_{ub}|$ inclusive*: $(4.31 \pm 0.25 \pm 0.16) \times 10^{-3}$
- $|V_{ub}|$ exclusive**: $(3.13 \pm 0.14 \pm 0.27) \times 10^{-3}$



Both SM and 2HDM (type II) scenario disfavoured if exclusive $|V_{ub}|$ is assumed:





"Preferred" value(s) for $\tan\beta/m_{H+}$ inconsistent with both $B \to D\tau\nu$ and $B \to D^{(*)}\tau\nu$

(also ruled out by other direct and indirect measurements)

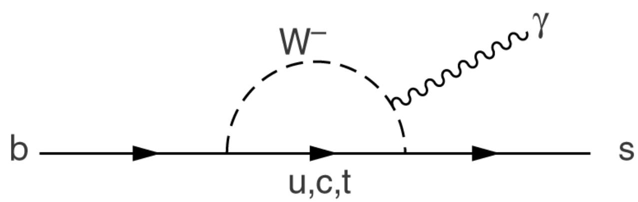
* BABAR arXiv:1112.0702

** BABAR Phys. Rev. **D83**, 032007 (2011).
BABAR Phys. Rev. **D83**, 052011 (2011).

FCNC processes

Electroweak FCNCs

$B \to X_{s/d}\,\gamma$



$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu)\, O_i(\mu)$$

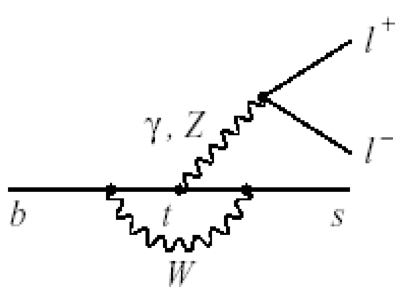
Products of field operators (non-perturbative hadronic matrix elements; Heavy quark expansion in inverse powers of m_b)

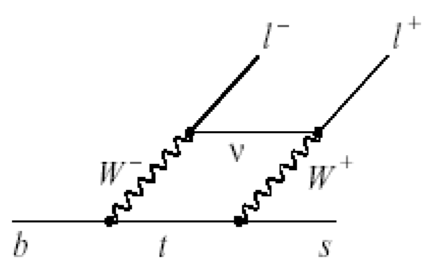
Wilson coefficients (calculated perturbatively; encode short-distance physics)

C_7 (Photon penguin)
Observables:
branching fractions E_γ spectrum, A_{CP}

New physics could result in a distinctive pattern of deviations in observables across a variety of related FCNC modes

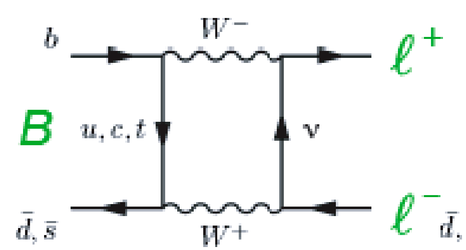
$B \to X_{s/d}\, l^+ l^-$

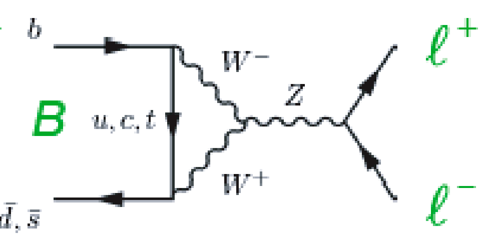




C_7 ,C_9 (Vector EW) and C_{10}
Observables:
(partial) branching fractions, A_{FB}, A_{CP}

$B^0_{s/d} \to l^+ l^-$

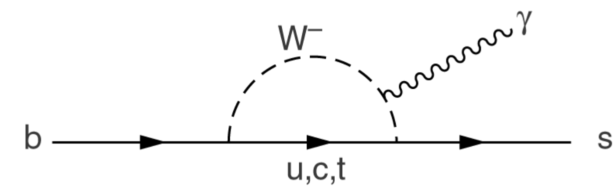




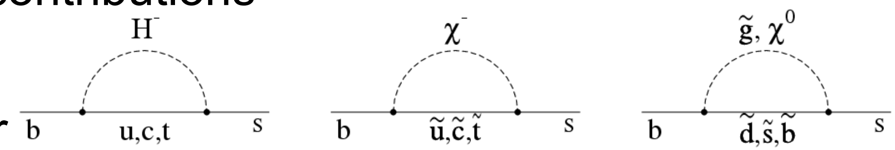
C_{10} (Axial vector EW)
Observables: branching fractions

$B \to X_s\gamma$

The process $b \to s\gamma$ occurs in SM via 1-loop photon penguin FCNC



- may be modified by new physics contributions also at one-loop
- photon energy spectrum useful for determination of HQET parameters



Obtain "inclusive" $B \to X_s\gamma$ by summing individual exclusive decay modes:

X_s modes consist of 1 or 3 kaons (including ≤1 K_s^0), ≤1 η, and ≤4 pions (including ≤2 π^0)

$1.6 < E^*_\gamma < 3.0$ GeV (in CM rest frame)

- Fit m_{ES} to a sum of 38 X_s final states

$$m_{\rm ES} = \sqrt{E^{*2}_{\rm beam} - p^{*2}_B}$$

SM expectation (NNLO)*:

$$\mathcal{B}(\bar{B} \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

Misiak et al. PRL 98 022002 (2007)

* For photon energy E_γ>1.6 GeV

Photon energy in B rest frame obtained from:

$$E^B_\gamma = \frac{m_B^2 - m_{X_s}^2}{2m_B}$$

$B \to X_s\gamma$

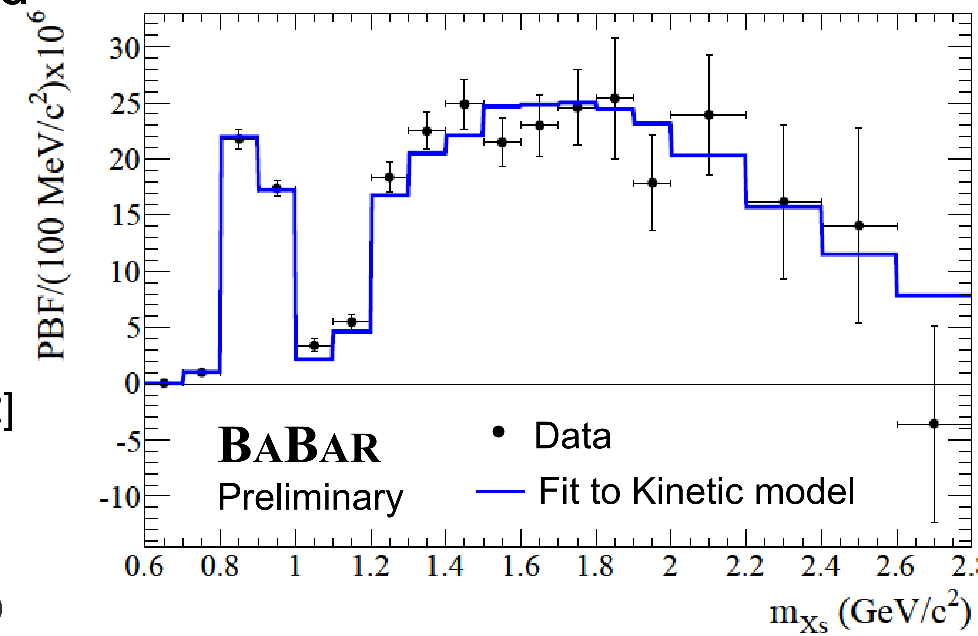
BABAR
Preliminary

Partial branching fractions extracted in bins of the X_s mass (m_{Xs})

- Spectrum fitted to models for extraction of HQET parameter values

	Kinetic Model [1]	Shape Function Model [2]
m_b	$4.568^{+0.038}_{-0.036}$ GeV/c^2	$4.579^{+0.032}_{-0.029}$ GeV/c^2
μ_π^2	$0.450^{+0.054}_{-0.054}$ GeV^2	$0.257^{+0.034}_{-0.039}$ GeV^2

[1] *Bensen et al. Nucl. Phys. B 710 371 (2005)*
[2] *Lange et al. PRD 72 073006 (2005)*



Partial branching fractions combined to obtain inclusive branching fraction (E_γ > 1.9 GeV):

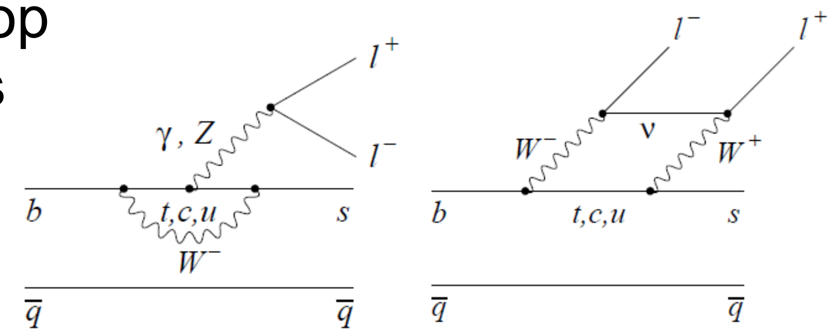
$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma>1.9\text{GeV}} = (3.29 \pm 0.19(\text{stat.}) \pm 0.48(\text{syst.})) \times 10^{-4}$$

– Good consistency with previous measurements

$B \to K^{(*)} l^+ l^-$

BABAR Submitted to PRD arXiv:1204.3933

$B \to K^{(*)} l^+ l^-$ decays occur in SM via one-loop FCNC processes with branching fractions of $O(10^{-6})$



- Recent ***BABAR*** measurements of branching fractions, direct CP asymmetries and angular distributions

Reconstruct exclusive final states:

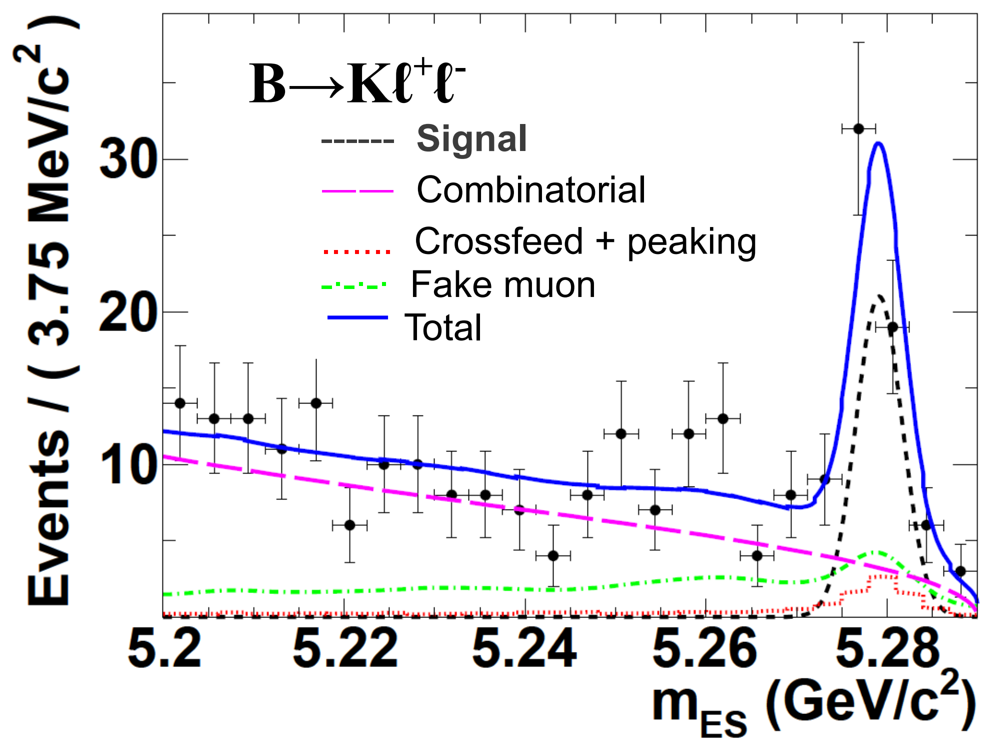
$K\ell^+\ell^-$:

$K_s^0 e^+e^-$, $K^+e^+e^-$, $K_s^0\mu^+\mu^-$, $K^+\mu^+\mu^-$

$K^*\ell^+\ell^-$:

$K_s^0\pi^+e^+e^-$, $K^+\pi^-e^+e^-$, $K_s^0\pi^+\mu^+\mu^-$, $K^+\pi^-\mu^+\mu^-$

$K^+\pi^0e^+e^-$ (only for angular analysis)

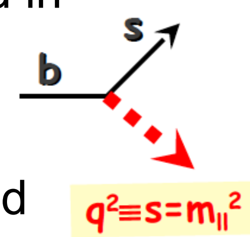


$B \to K^{(*)} l^+ l^-$

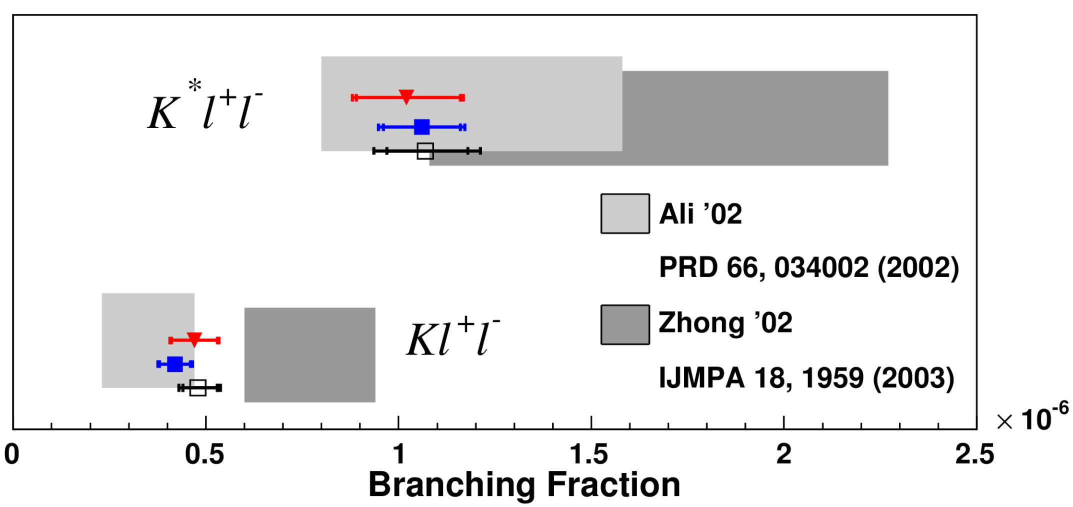
BABAR
Submitted to PRD
arXiv:1204.3933

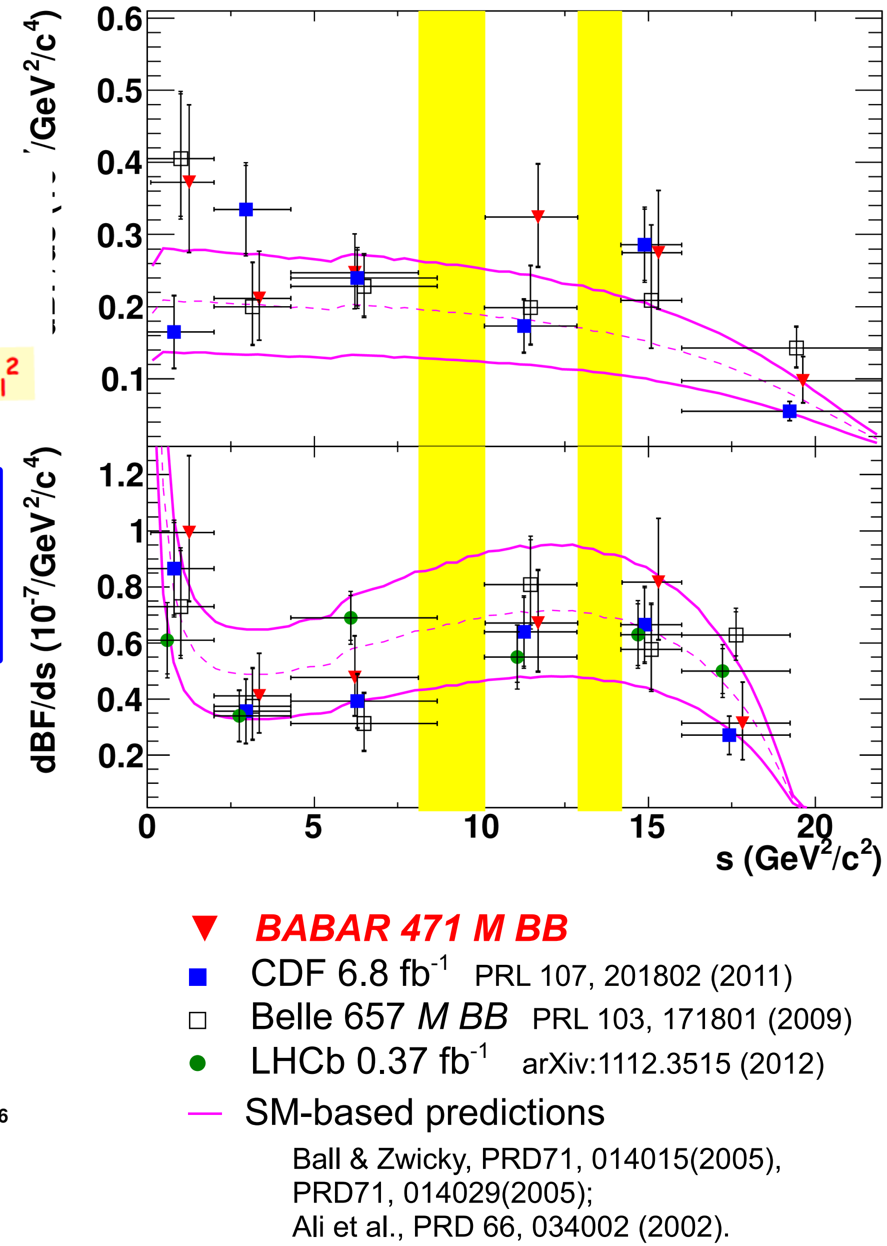
Branching fraction results:

- Partial branching fraction measured in bins of q^2 excluding J/ψ and $\psi(2S)$ regions
- Total branching fractions determined over entire q^2 range



$$\mathcal{B}(B \to K\ell^+\ell^-) = (4.7 \pm 0.6 \pm 0.2) \times 10^{-7},$$
$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (10.2^{+1.4}_{-1.3} \pm 0.5) \times 10^{-7}.$$





$B \to K^{(*)} l^+ l^-$

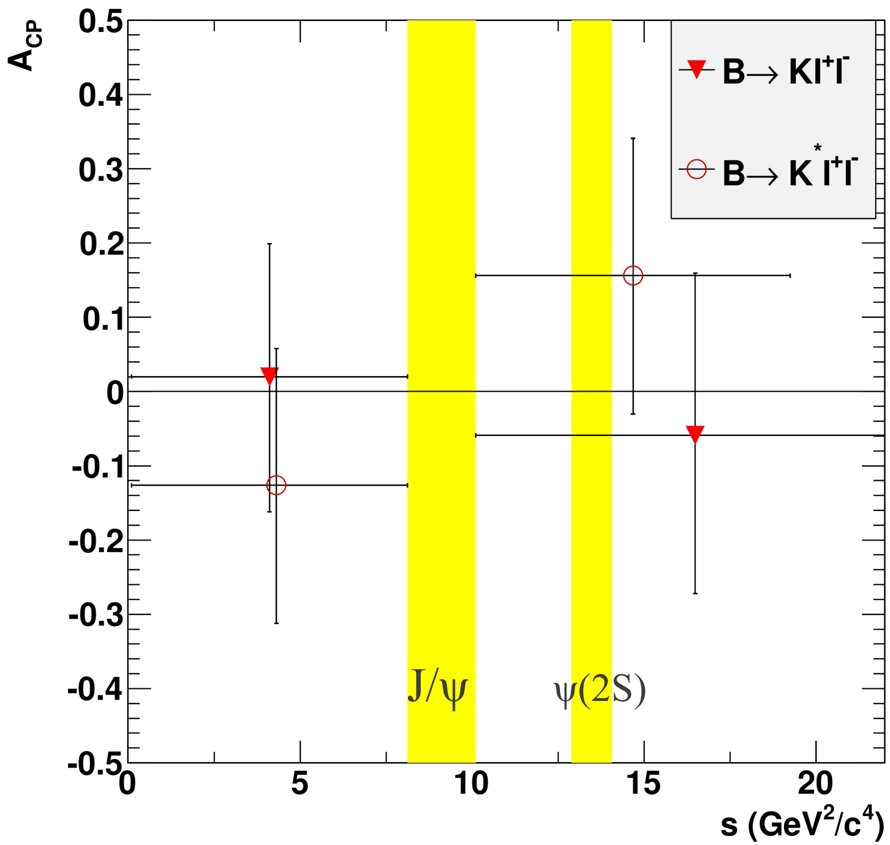
BABAR
Submitted to PRD
arXiv:1204.3933

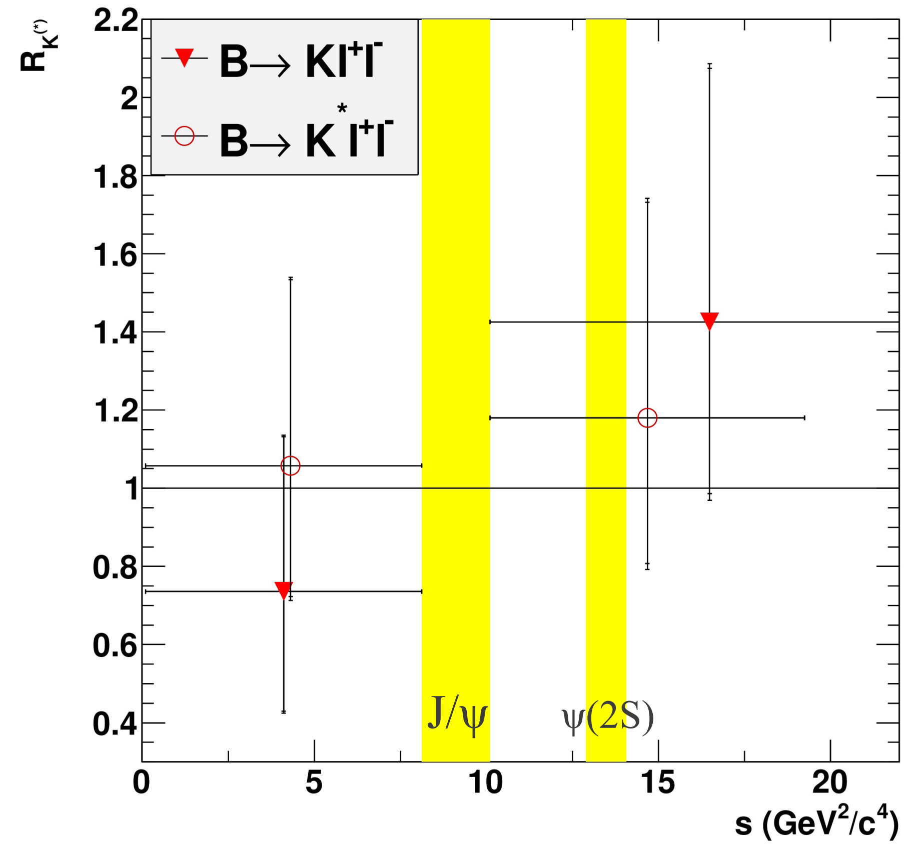
- Direct CP asymmetry consistent with SM expectation of zero

$$\mathcal{A}_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \mathcal{B}(B \to K^{(*)}\ell^+\ell^-)}$$

- No evidence of lepton flavour asymmetry

$$\mathcal{R}_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$





$B \to K^{(*)} \ell^+ \ell^-$

BABAR
Submitted to PRD
arXiv:1204.3933

SM expectation for isospin asymmetries is ***O*(1%)** Feldmann & Matias, JHEP 0301, 074 (2003).

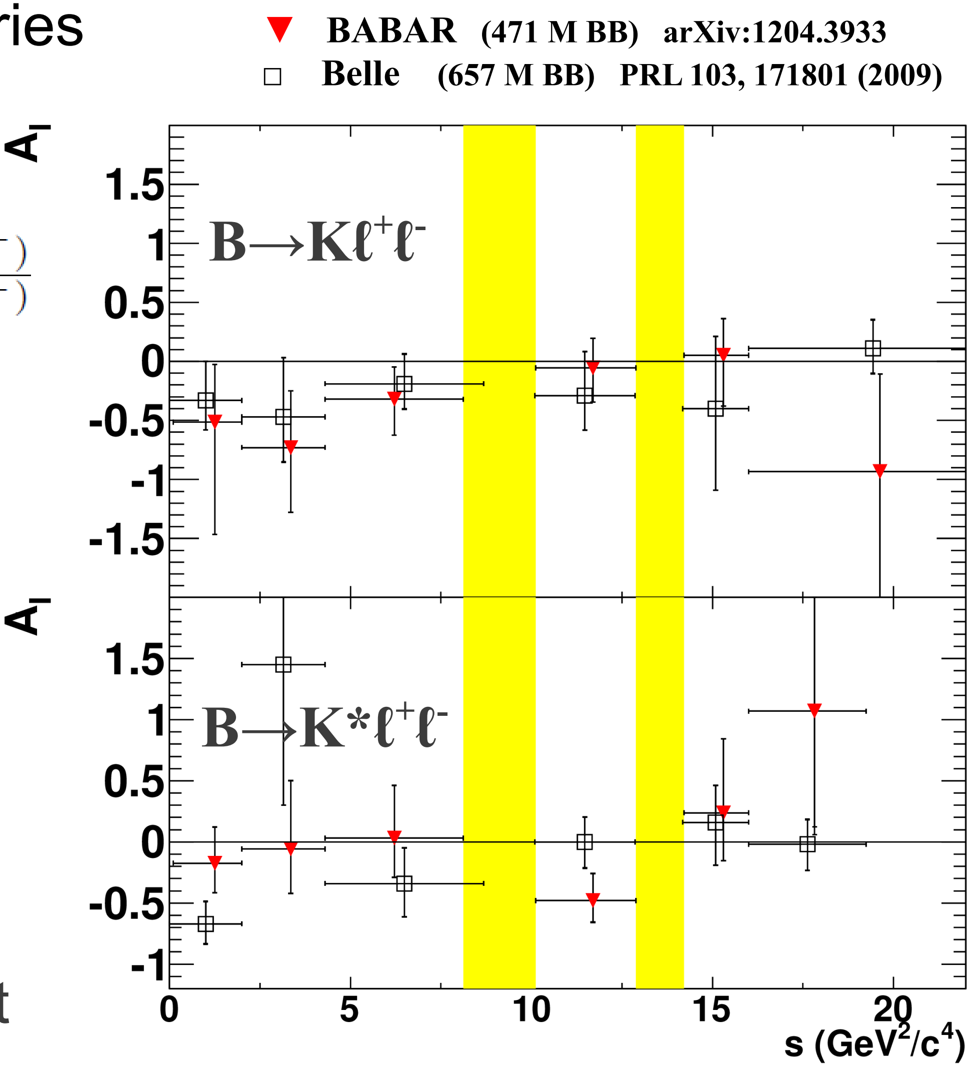
$$\mathcal{A}_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}$$

$$r_\tau \equiv \tau_{B^0}/\tau_{B^+} = 1/(1.071 \pm 0.009)$$

- Indication of possible asymmetry in region below J/ψ :

$$\mathcal{A}_I^{\rm low}(B \to K\ell^+\ell^-) = -0.58^{+0.29}_{-0.37} \pm 0.02 \quad [2.10\sigma]$$
$$\mathcal{A}_I^{\rm low}(B \to K^*\ell^+\ell^-) = -0.25^{+0.20}_{-0.17} \pm 0.03 \quad [1.15\sigma]$$

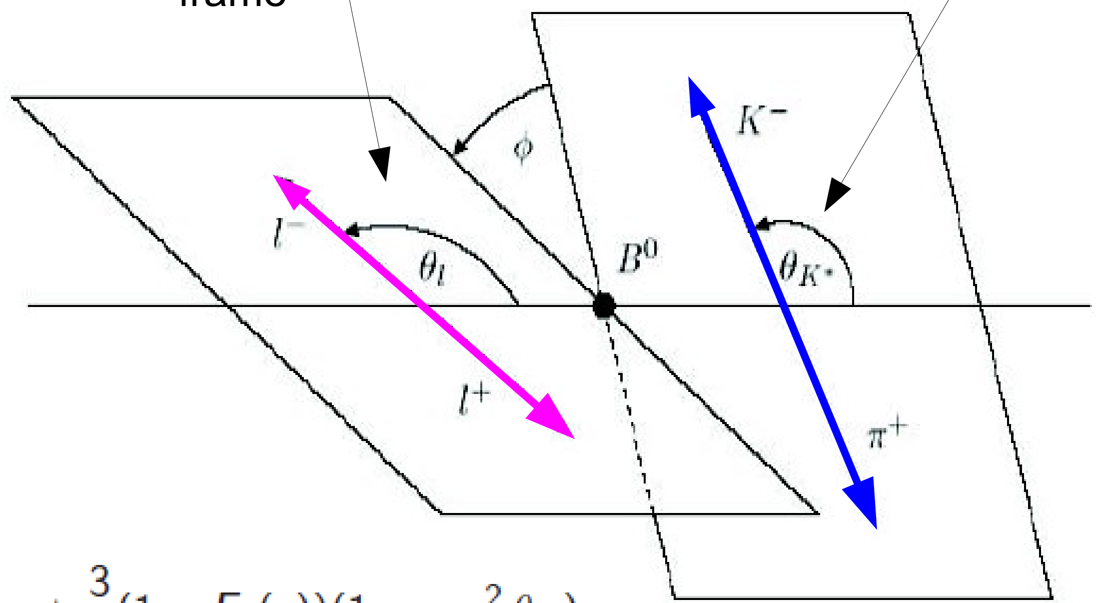
$$(0.1 < s < 8.12\ \mathrm{GeV}^2/c^4)$$



Consistent with SM predictions at **2.1σ** and **1.2σ** level respectively

$B \to K^{(*)} \ell^+ \ell^-$

Fit angular distributions of $K^{(*)}$ and dilepton system to extract two observables:



- K* longitudinal polarization fraction ***F_L***

$$\frac{1}{\Gamma(s)}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L(s)\cos^2\theta_K + \frac{3}{4}(1-F_L(s))(1-\cos^2\theta_K)$$

- $\ell^+\ell^-$ forward-backward asymmetry ***A_{FB}***

$$\frac{1}{\Gamma(s)}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_L(s)(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L(s))(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

$B \rightarrow K^{(*)}\ell^+\ell^-$

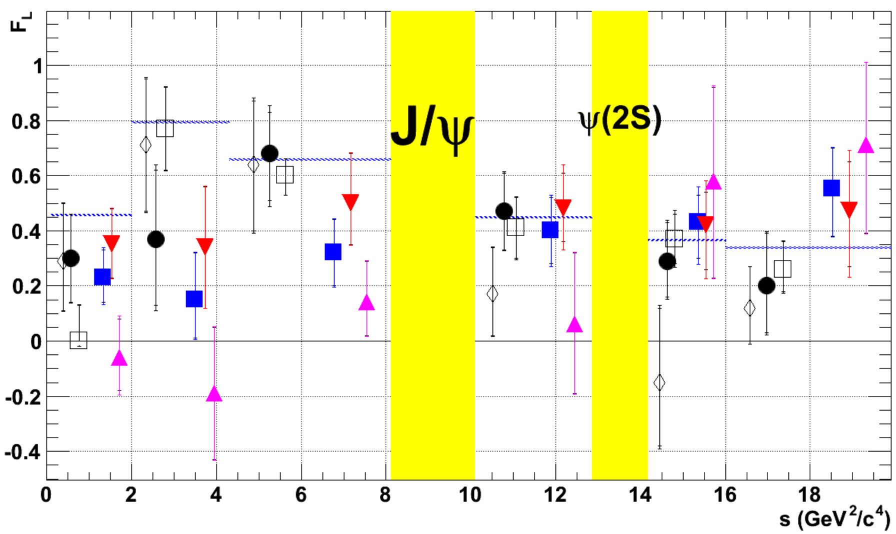
BABAR
Preliminary

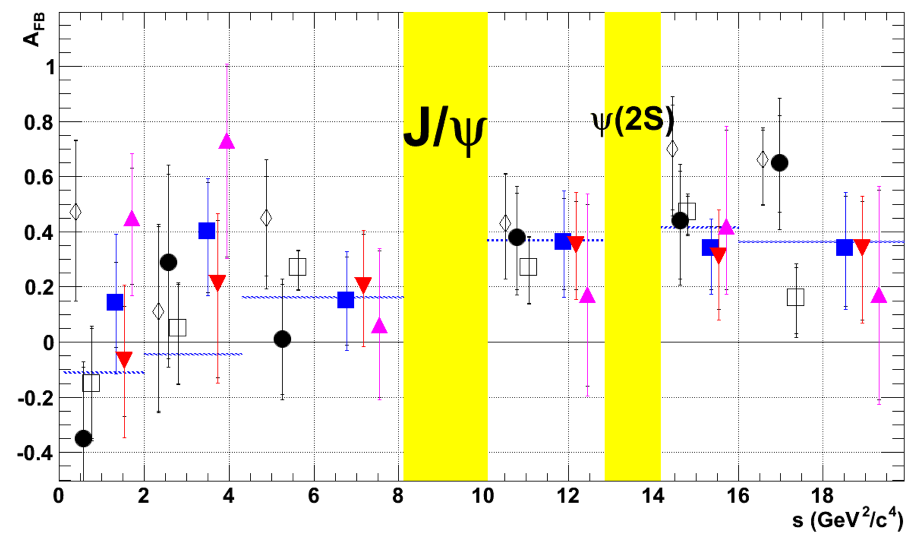
Recent preliminary BABAR results based on full data sample

- Most precise non-LHCb results to-date

■ $K^*\ell^+\ell^-$
▼ $K^{*0}\ell^+\ell^-$ } BABAR *471 M BB*
▲ $K^{*+}\ell^+\ell^-$

● CDF 6.8 fb^{-1} PRL 108, 081807 (2012)
◊ Belle 657 *M BB* PRL 103, 171801 (2009)
□ LHCb 0.37 fb^{-1} arXiv:1112.3515 (2012)
- - - Standard Model *





- Generally good agreement with SM and other experiments
  - some mild tension in low-s region

* *Ali et al. PRD 61, 074024 (2000)*
Buchalla et al. PRD 63, 014015 (2001)
Ali et al. PRD 66, 034002 (2002)
Krüger et al. PRD 61, 114028 (2002)
Krüger & Matias PRD71, 094009 (2005)
Ball & Zwicky, PRD71, 014029(2005)

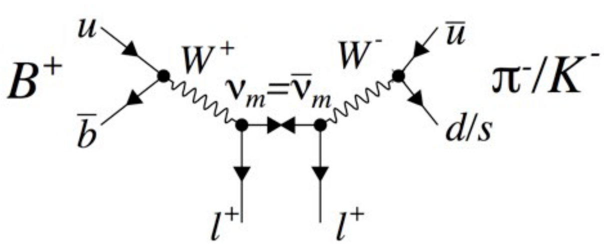
Rare & forbidden decays

$B^+ \to h^- \ell^+ \ell^+$ (h=K,π)

BABAR
PRD, 85, 071103(R) (2012)

Lepton number not explicitly conserved in many SM extensions

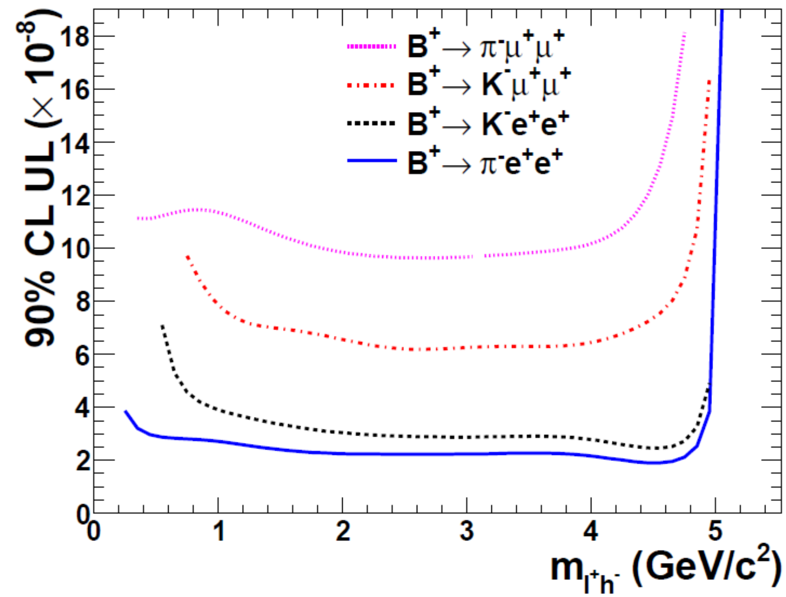
- LNV in $B^+ \to h^- \ell^+ \ell^+$ is ΔL =2 process which can occur via Majorana neutrinos



  – complementary to 0vββ searches

BABAR search for $B^+ \to h^- \ell^+ \ell^+$ (h=K,π)

- Event selection similar to $B \to K^{(*)} l^+ l^-$ analysis



Mode	$\mathcal{B}$ $(\times 10^{-8})$	$\mathcal{B}_{UL}$ $(\times 10^{-8})$
$B^+ \to \pi^- e^+ e^+$	$0.27^{+1.1}_{-1.2} \pm 0.1$	2.3
$B^+ \to K^- e^+ e^+$	$0.49^{+1.3}_{-0.8} \pm 0.1$	3.0
$B^+ \to \pi^- \mu^+ \mu^+$	$0.03^{+5.1}_{-3.2} \pm 0.6$	10.7
$B^+ \to K^- \mu^+ \mu^+$	$0.45^{+3.2}_{-2.7} \pm 0.4$	6.7

- Best electron channel results
- Sensitivity comparable to LHCb in $\mu^+\mu^-$ modes:

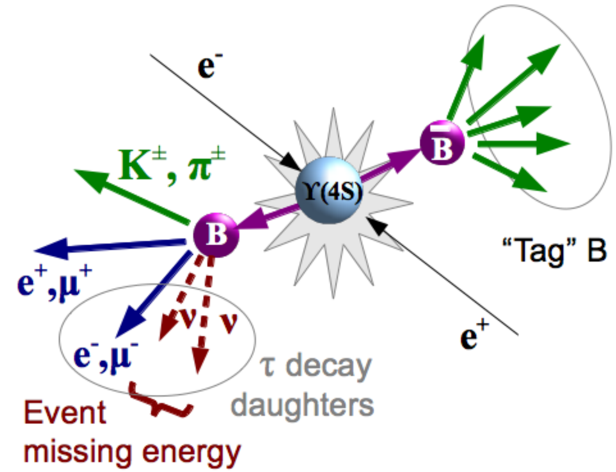
LHCb: $B(B^+ \to X^- \mu^+ \mu^+) < 1.3 \times 10^{-8} – 2.6 \times 10^{-6}$ (41 pb^{-1})
PRL 108, 101601 (2012); arXiv:1201.5600

$B^{\pm}\to h^{\pm}\tau^{+}l^{-}$ (h=K,π)

BABAR
Submitted to PRD
arXiv:1204.2852

Search for lepton flavour violating B decays with a 3rd generation charged lepton (τ)

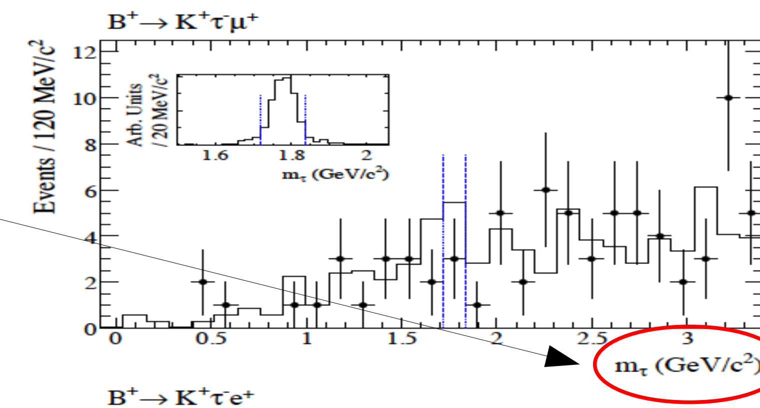
- possible NP enhancement in models with 2nd - 3rd generation mixing or mass dependent couplings

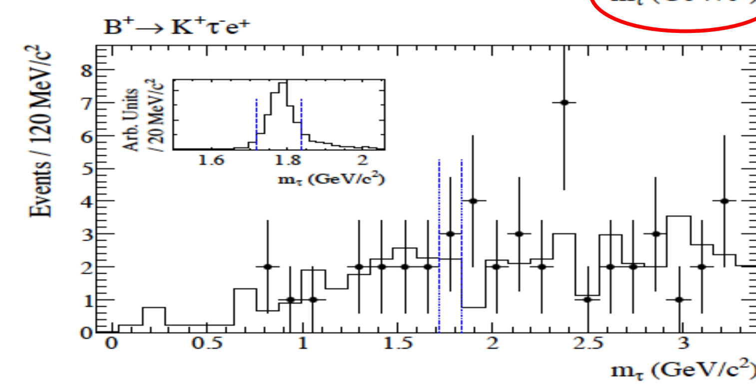


Missing energy signature necessitates "hadronic tag reconstruction" analysis

- 1-prong τ decay modes (e/μ/π)
- 4-vector of τ determined from h-l-B combination

Mode	$\mathcal{B}(B\to h\tau\ell)$ ($\times 10^{-5}$) central value	90% C.L. UL
$B^+\to K^+\tau\mu$	$0.0\ ^{+2.7}_{-1.4}$	< 4.8
$B^+\to K^+\tau e$	$-0.6\ ^{+1.7}_{-1.4}$	< 3.0
$B^+\to \pi^+\tau\mu$	$0.5\ ^{+3.8}_{-3.2}$	< 7.2
$B^+\to \pi^+\tau e$	$2.3\ ^{+2.8}_{-1.7}$	< 7.5





Model independent limits on NP scale in τ-μ flavour changing operators*:

$\Lambda_{bd}>11$ TeV
$\Lambda_{bs}>15$ TeV

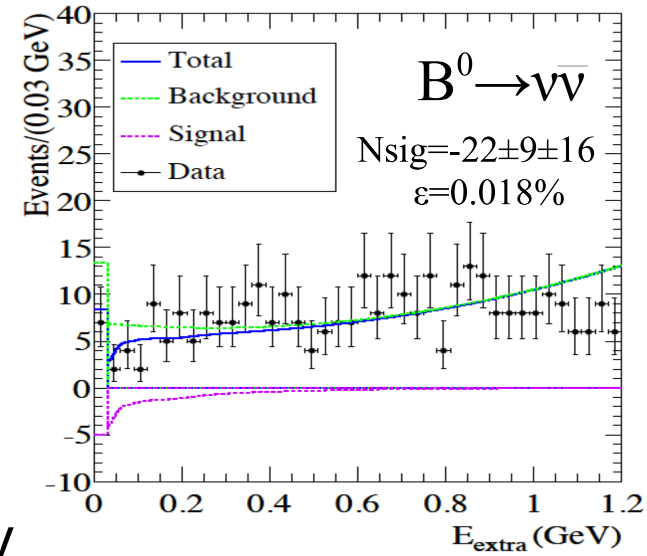
* PRD 66, 053002 (2002)

$B^0 \to \nu\bar{\nu}(\gamma)$ ("invisible")

BABAR
Preliminary
470M $B\bar{B}$

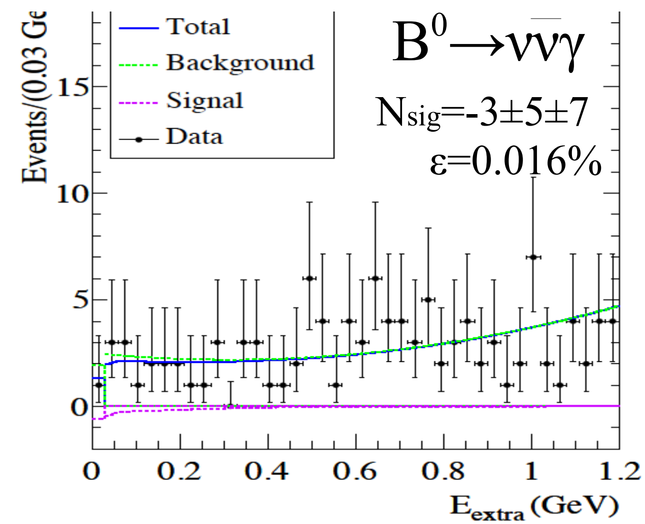
$B^0 \to \nu\bar{\nu}$ strongly helicity suppressed FCNC in SM

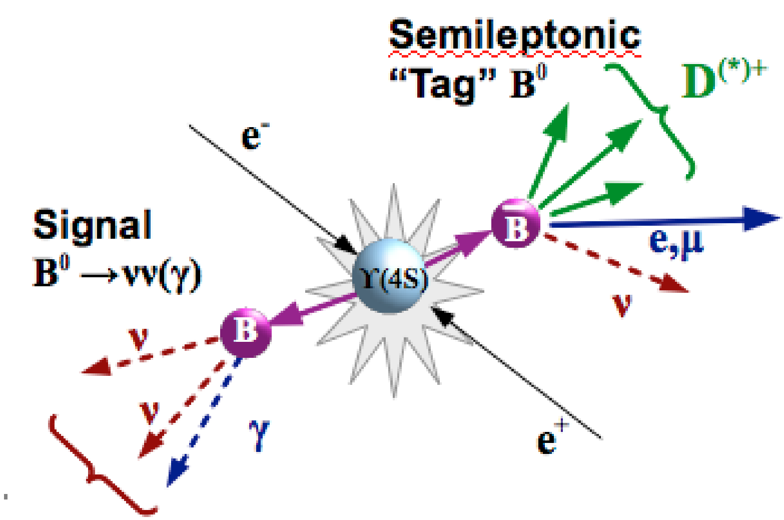
- Presence of energetic photon removes suppression
  $B(B^0 \to \nu\bar{\nu}\gamma) \sim 10^{-9}$
- Possibility of enhancement to $\sim 10^{-7}$-10^{-6} in some new physics models (RPV SUSY, LED models)



Semileptonic tag reconstruction method to identify B decays with little or no additional detector activity

- Require no additional charged tracks, and select events with limited $E_{extra} \equiv \sum E_{calorimeter}$





~order of magnitude improvement over previous limits:

$$\mathcal{B}(B^0 \to \text{invisible}) < 2.4 \times 10^{-5}$$
$$\mathcal{B}(B^0 \to \text{invisible} + \gamma) < 1.7 \times 10^{-5}$$

Conclusion

Many recent new results from ***BABAR*** on decays with potential sensitivity to new physics!

- Competitive new measurements of $b \rightarrow s$ FCNC processes based on full data statistics
- Stringent new limits on rare and forbidden B decays
- Interesting(?) discrepancies in tree-level leptonic and semileptonic decays

Backup slides

$B \to D^{(*)}\tau\nu$

BABAR
arXiv:1205.5442

Signal events possess secondary e or μ from $\tau \to l\nu\nu$ while normalization modes have primary lepton from $B \to D^{*} l\nu$

- $p_e > 300$ MeV $p_\mu > 200$ MeV (improved particle identification!)

Four $B \to D^{(*)}\tau\nu$ signal decay modes considered: D^0, D^{*0}, D^+, D^{*+}

- D^0, D^+ exclusively reconstructed in one of several decay modes:

$D^0 \to K^-\pi^+$
$D^0 \to K^-K^+$
$D^0 \to K^-\pi^+\pi^0$
$D^0 \to K^-\pi^+\pi^-\pi^+$
$D^0 \to K^0_S\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^+$
$D^+ \to K^-\pi^+\pi^+\pi^0$
$D^+ \to K^0_S\pi^+$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$
$D^+ \to K^0_S\pi^+\pi^0$
$D^+ \to K^0_S K^+$

$D^{*0} \to D^0\pi^0,\ D^0\gamma$

$D^{*+} \to D^0\pi^+,\ D^+\pi^0$

Calorimeter energy not associated with tag- or signal-B

  - Kinematic fit with vertex constraint to reduce combinatorial backgrounds

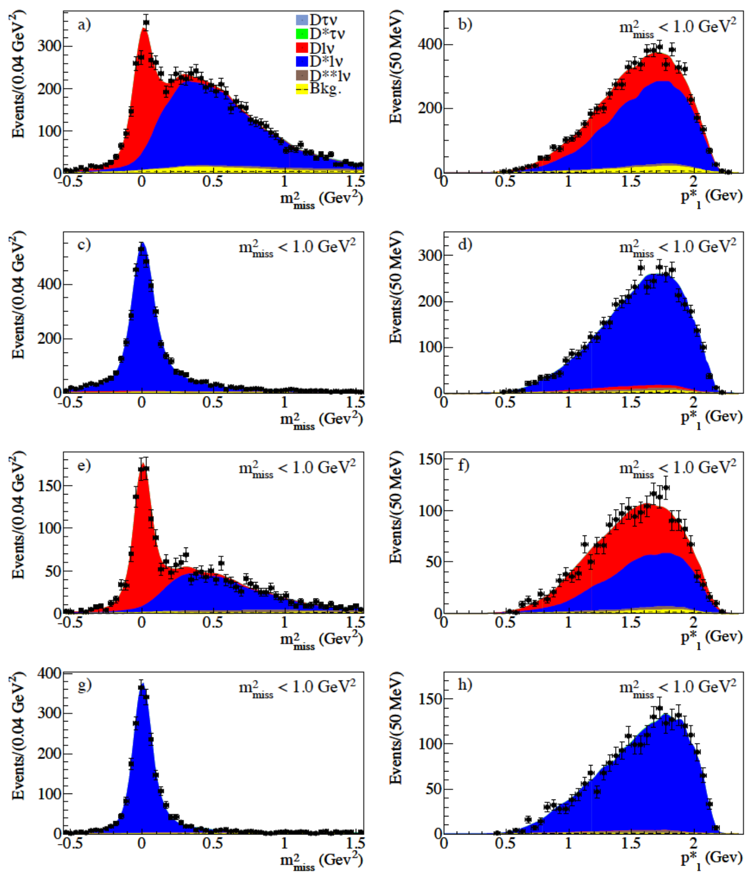
- Select candidate ($B_{tag} + B \to D^{(*)}\tau\nu$) with lowest E_{extra}

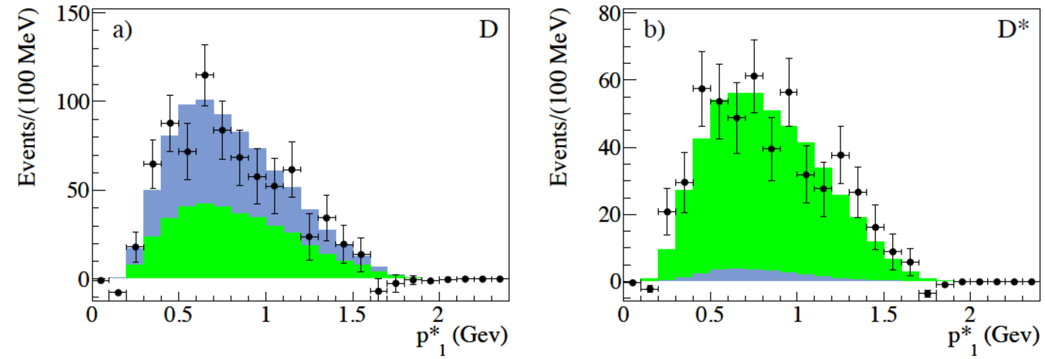
Boosted decision tree used to further suppress combinatorial and $B \to D^{**}l\nu$ backgrounds:

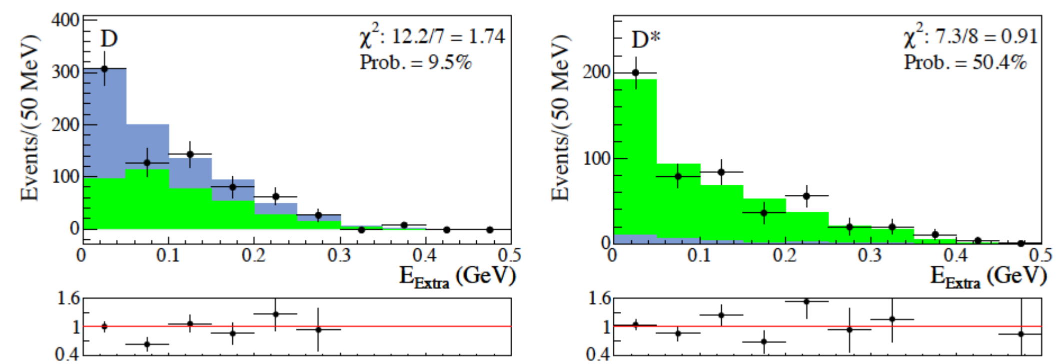
  - Inputs: N_{tracks}, $\cos\theta_T$, E_{extra} and reconstructed intermediate masses

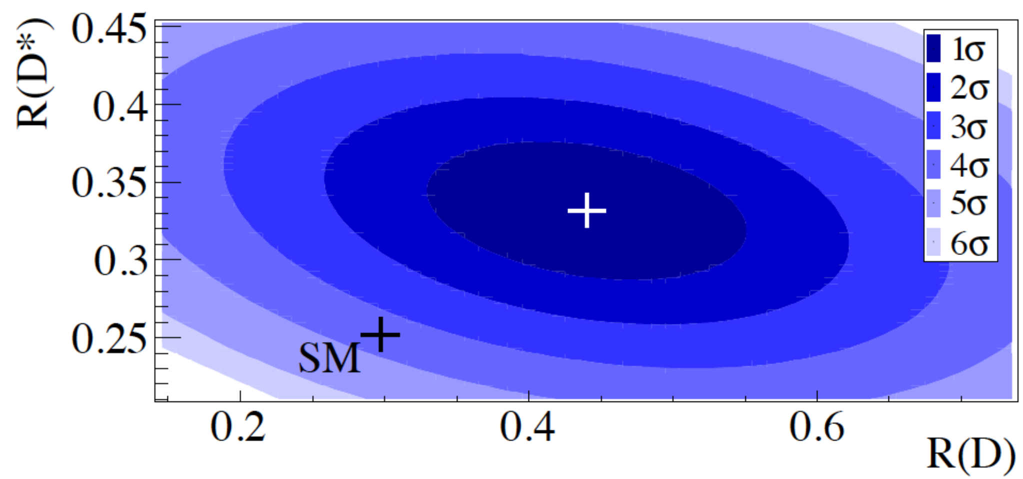
$B \to D^{(*)} \tau \nu$

BABAR
arXiv:1205.5442





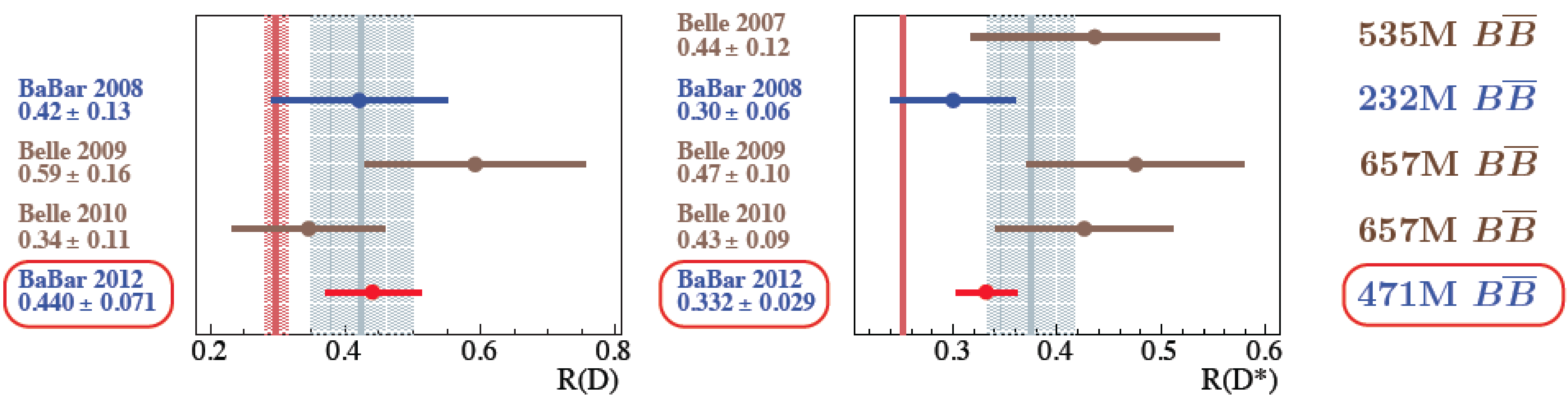




$B \to D^{(*)} \tau \nu$

BABAR
arXiv:1205.5442

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |\mathbf{p}| q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2 \left[\left(|H_{++}|^2+|H_{--}|^2+|H_{00}|^2\right)\left(1+\frac{m_\tau^2}{2q^2}\right)+\frac{3}{2}\frac{m_\tau^2}{q^2}|H_{0t}|^2\right]$$

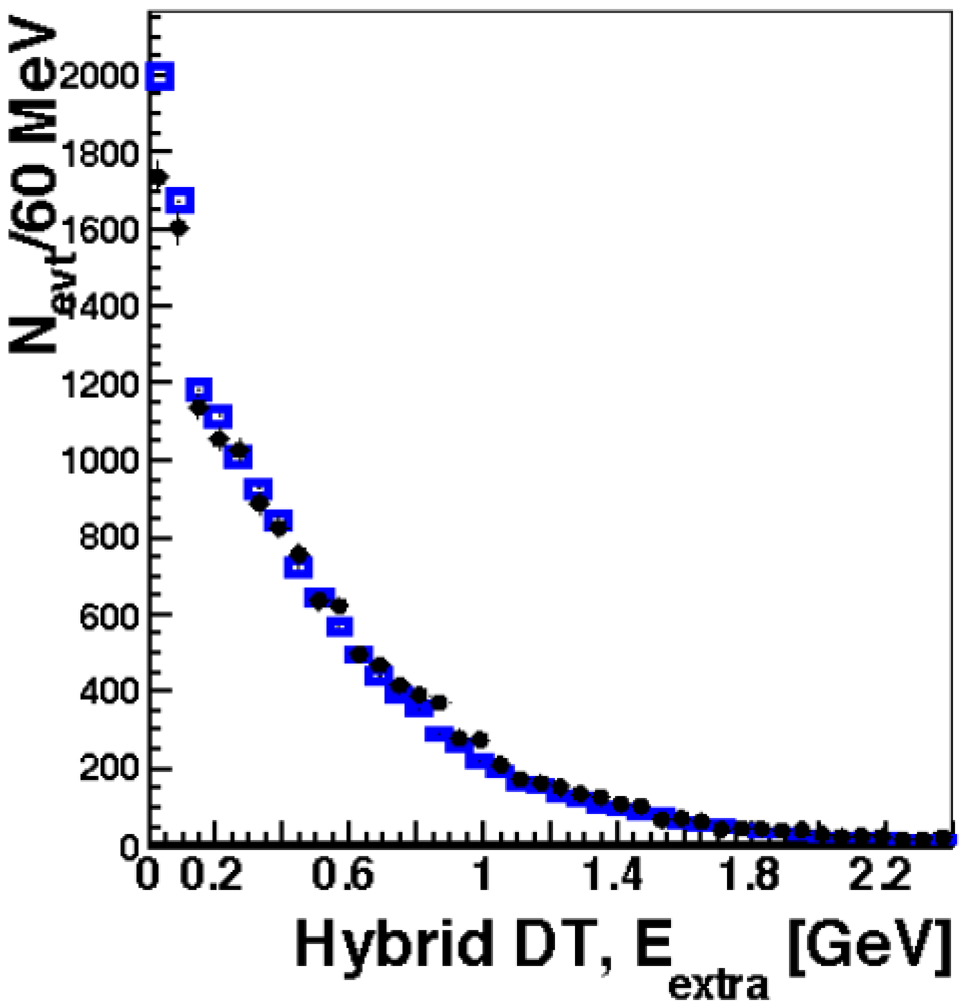


Average does not include new BABAR results

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

BABAR Preliminary

Decay Mode	$\mathcal{B}(\times 10^{-4})$
$\tau^+ \to e^+ \nu \bar{\nu}$	$0.35^{+0.84}_{-0.73}$
$\tau^+ \to \mu^+ \nu \bar{\nu}$	$1.12^{+0.90}_{-0.78}$
$\tau^+ \to \pi^+ \nu$	$3.69^{+1.42}_{-1.22}$
$\tau^+ \to \rho^+ \nu$	$3.78^{+1.65}_{-1.45}$
combined	$1.83^{+0.53}_{-0.49}$



$B^{\pm} \to h^{\pm}\tau^{+}\ell^{-}$

BABAR
Submitted to PRD
arXiv:1204.2852

Mode	τ channel	b_i	n_i	$\epsilon_{h\tau\ell,i}$	$\mathcal{B}(B \to h\tau\ell)$ $(\times 10^{-5})$ central value	90% C.L. UL
$B^+ \to K^+\tau^-\mu^+$	e	0.4 ± 0.2	2	$(2.6 \pm 0.2)\%$	$0.8\ ^{+1.9}_{-1.4}$	< 4.5
	μ	0.3 ± 0.2	0	$(3.2 \pm 0.4)\%$		
	π	1.8 ± 0.8	1	$(4.1 \pm 0.4)\%$		
$B^+ \to K^+\tau^+\mu^-$	e	0.2 ± 0.1	0	$(3.7 \pm 0.3)\%$	$-0.4\ ^{+1.4}_{-0.9}$	< 2.8
	μ	0.2 ± 0.1	0	$(3.6 \pm 0.7)\%$		
	π	6.9 ± 1.5	11	$(9.1 \pm 0.5)\%$		
$B^+ \to K^+\tau^-e^+$	e	0.6 ± 0.1	2	$(2.2 \pm 0.2)\%$	$0.2\ ^{+2.1}_{-1.0}$	< 4.3
	μ	0.1 ± 0.1	0	$(2.7 \pm 0.6)\%$		
	π	1.5 ± 0.5	1	$(4.8 \pm 0.6)\%$		
$B^+ \to K^+\tau^+e^-$	e	0.8 ± 0.5	0	$(2.8 \pm 1.1)\%$	$-1.3\ ^{+1.5}_{-1.8}$	< 1.5
	μ	0.1 ± 0.1	0	$(3.2 \pm 0.7)\%$		
	π	4.6 ± 1.3	4	$(8.7 \pm 1.2)\%$		
$B^+ \to \pi^+\tau^-\mu^+$	e	0.9 ± 0.6	0	$(2.3 \pm 0.2)\%$	$0.4\ ^{+3.1}_{-2.2}$	< 6.2
	μ	1.1 ± 0.4	2	$(2.9 \pm 0.4)\%$		
	π	3.3 ± 0.9	4	$(2.8 \pm 0.2)\%$		
$B^+ \to \pi^+\tau^+\mu^-$	e	2.1 ± 0.5	2	$(3.8 \pm 0.3)\%$	$0.0\ ^{+2.6}_{-2.0}$	< 4.5
	μ	3.6 ± 0.9	4	$(4.8 \pm 0.3)\%$		
	π	25 ± 3	23	$(9.1 \pm 0.6)\%$		
$B^+ \to \pi^+\tau^-e^+$	e	0.1 ± 0.1	1	$(2.0 \pm 0.8)\%$	$2.8\ ^{+2.4}_{-1.9}$	< 7.4
	μ	0.4 ± 0.2	1	$(2.8 \pm 0.3)\%$		
	π	6.0 ± 1.4	7	$(5.8 \pm 0.3)\%$		
$B^+ \to \pi^+\tau^+e^-$	e	1.0 ± 0.4	0	$(2.9 \pm 0.3)\%$	$-3.1\ ^{+2.4}_{-2.1}$	< 2.0
	μ	3.0 ± 1.2	2	$(4.6 \pm 0.4)\%$		
	π	5.7 ± 2.5	3	$(3.7 \pm 1.0)\%$		

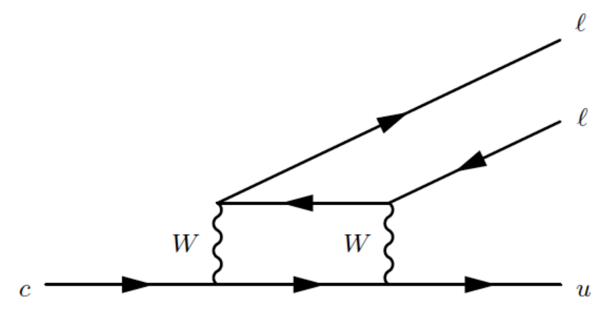
Rare charm decays

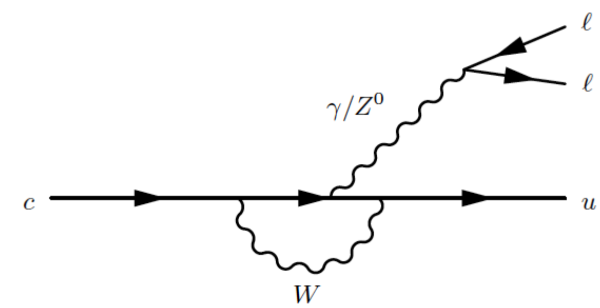
Phys.Rev. D84 (2011) 072006
arXiv:1107.4465

Search for decays of the form

$$X_c^+ \rightarrow h^{\pm}\ell^{\mp}\ell^{(\prime)+}$$

where X_c^+ is D^+, D_s^+ or Λ_c^+
and h is K, π or p (for Λ_c^+)





- Various lepton charge/flavour combinations represent (highly GIM suppressed) SM decays, LFV and LNV decays

SM predictions for GIM-suppressed modes ~10^{-8} but potentially enhanced by up to 3 orders of magnitude in NP models

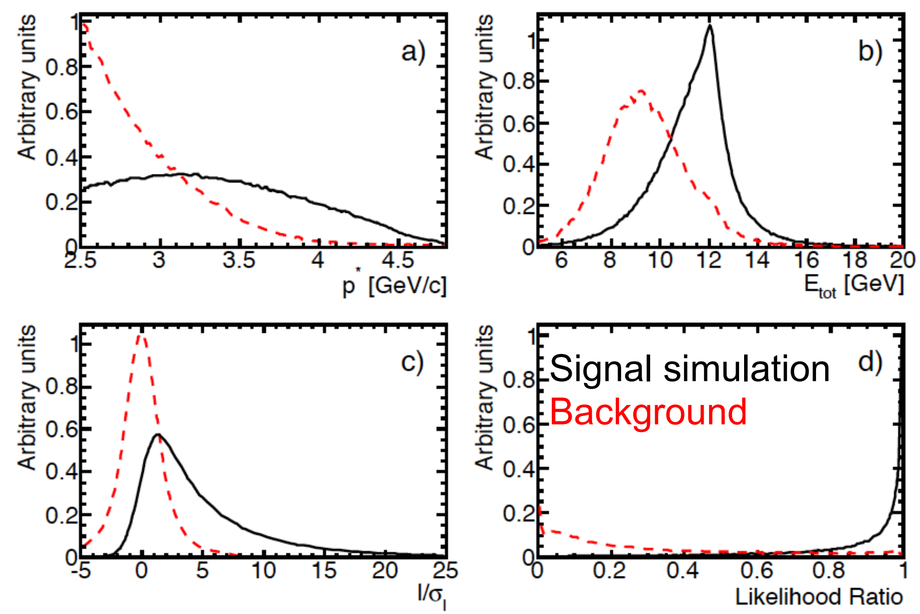
PRD 66, 014009 (2002)
PRD 64, 114009 (2001)

- Complementary new physics sensitivity to rare B decays via d-type FCNC loops

Rare charm decays

Searches based on 384fb^{-1} of BABAR data ("onpeak" + "offpeak")

- exclusively reconstruct 3-track final states, requiring two identified leptons
- Veto B decays by requiring D^+, D_s^+ or Λ_c^+ candidate to have p* >2.5 GeV/c
- QED backgrounds suppressed by requiring >4 tracks in the event
  - Long distance contributions from $D_{(s)}^+ \rightarrow \pi^+\phi(\rightarrow l^+l^-)$ removed by veto on ϕ mass region
  - Likelihood ratio to suppress remaining background →



Rare charm decays

Signal yields obtained from fit to hll' invariant mass

- Normalized to rates for known 3-body hadronic modes with similar kinematics

Decay mode	Yield (events)	Eff. (%)	BR UL 90% CL (10^{-4})	BF UL 90% CL (10^{-6})
$D^+ \to \pi^+ e^+ e^-$	$-3.9 \pm 1.6 \pm 1.7$	1.56	3.9	1.1
$D^+ \to \pi^+ \mu^+ \mu^-$	$-0.2 \pm 2.8 \pm 0.9$	0.46	24	6.5
$D^+ \to \pi^+ e^+ \mu^-$	$-2.9 \pm 3.4 \pm 2.4$	1.21	11	2.9
$D^+ \to \pi^+ \mu^+ e^-$	$3.6 \pm 4.3 \pm 1.3$	1.54	13	3.6
$D_s^+ \to \pi^+ e^+ e^-$	$8 \pm 34 \pm 8$	6.36	5.4	13
$D_s^+ \to \pi^+ \mu^+ \mu^-$	$20 \pm 15 \pm 4$	1.21	18	43
$D_s^+ \to \pi^+ e^+ \mu^-$	$-3 \pm 11 \pm 3$	2.16	4.9	12
$D_s^+ \to \pi^+ \mu^+ e^-$	$9.3 \pm 7.3 \pm 2.8$	1.50	8.4	20
$D^+ \to K^+ e^+ e^-$	$-3.7 \pm 2.9 \pm 3.3$	2.88	3.7	1.0
$D^+ \to K^+ \mu^+ \mu^-$	$-1.3 \pm 2.8 \pm 1.1$	0.65	16	4.3
$D^+ \to K^+ e^+ \mu^-$	$-4.3 \pm 1.8 \pm 0.6$	1.44	4.3	1.2
$D^+ \to K^+ \mu^+ e^-$	$3.2 \pm 3.8 \pm 1.2$	1.74	9.9	2.8
$D_s^+ \to K^+ e^+ e^-$	$-5.7 \pm 5.8 \pm 2.0$	3.20	1.6	3.7
$D_s^+ \to K^+ \mu^+ \mu^-$	$4.8 \pm 5.9 \pm 1.2$	0.85	9.1	21
$D_s^+ \to K^+ e^+ \mu^-$	$9.1 \pm 6.0 \pm 2.8$	1.74	5.7	14
$D_s^+ \to K^+ \mu^+ e^-$	$3.4 \pm 6.4 \pm 3.5$	2.08	4.2	9.7
$\Lambda_c^+ \to p e^+ e^-$	$4.0 \pm 6.5 \pm 2.8$	5.52	0.8	5.5
$\Lambda_c^+ \to p \mu^+ \mu^-$	$11.1 \pm 5.0 \pm 2.5$	0.86	6.4	44
$\Lambda_c^+ \to p e^+ \mu^-$	$-0.7 \pm 2.9 \pm 0.9$	1.10	1.6	9.9
$\Lambda_c^+ \to p \mu^+ e^-$	$6.2 \pm 4.6 \pm 1.8$	1.37	2.9	19

Decay mode	Yield (events)	Eff. (%)	BR UL 90% CL (10^{-4})	BF UL 90% CL (10^{-6})
$D^+ \to \pi^- e^+ e^+$	$4.7 \pm 4.7 \pm 0.5$	3.16	6.8	1.9
$D^+ \to \pi^- \mu^+ \mu^+$	$-3.1 \pm 1.2 \pm 0.5$	0.70	7.5	2.0
$D^+ \to \pi^- \mu^+ e^+$	$-5.1 \pm 4.2 \pm 2.0$	1.72	7.4	2.0
$D_s^+ \to \pi^- e^+ e^+$	$-5.7 \pm 14. \pm 3.4$	6.84	1.8	4.1
$D_s^+ \to \pi^- \mu^+ \mu^+$	$0.6 \pm 5.1 \pm 2.7$	1.05	6.2	14
$D_s^+ \to \pi^- \mu^+ e^+$	$-0.2 \pm 7.9 \pm 0.6$	2.23	3.6	8.4
$D^+ \to K^- e^+ e^+$	$-2.8 \pm 2.4 \pm 0.2$	2.67	3.1	0.9
$D^+ \to K^- \mu^+ \mu^+$	$7.2 \pm 5.4 \pm 1.6$	0.80	37	10
$D^+ \to K^- \mu^+ e^+$	$-11.6 \pm 4.0 \pm 3.1$	1.52	6.8	1.9
$D_s^+ \to K^- e^+ e^+$	$2.3 \pm 7.9 \pm 3.3$	4.10	2.1	5.2
$D_s^+ \to K^- \mu^+ \mu^+$	$-2.3 \pm 5.0 \pm 2.8$	0.98	5.3	13
$D_s^+ \to K^- \mu^+ e^+$	$-14.0 \pm 8.4 \pm 2.0$	2.26	2.4	6.1
$\Lambda_c^+ \to \overline{p} e^+ e^+$	$-1.5 \pm 4.2 \pm 1.5$	5.14	0.4	2.7
$\Lambda_c^+ \to \overline{p} \mu^+ \mu^+$	$-0.0 \pm 2.1 \pm 0.6$	0.94	1.4	9.4
$\Lambda_c^+ \to \overline{p} \mu^+ e^+$	$10.1 \pm 5.8 \pm 3.5$	2.50	2.3	16

No significant signals seen

- Establish 90% CL limits ranging from (0.9×10^{-6}) - (44×10^{-6})
- First limits on Λ_c^+ modes

The *BABAR* experiment

Large data samples corresponding to

- **432 fb^{-1}** Υ(4S) "onpeak"
- **53 fb^{-1}** "offpeak"
  - collected ~40MeV below Υ(4S) peak
- Also samples of "narrow Υ" events:
  - 122 x 10^6 Υ(3S) decays
  - 99 x 10^6 Υ(2S) decays