Rare B meson decays involving leptons at BaBar

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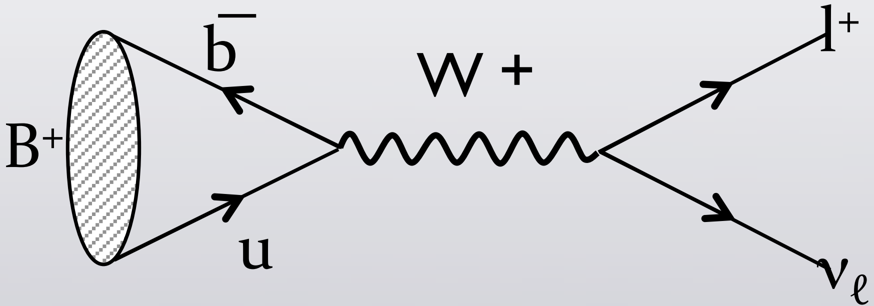
Outline

- Untagged $B \to e/\mu\ \nu$
- Semileptonic tagged $B \to \tau\ \nu,\ \mu\ \nu,\ e\ \nu$
- Hadronic tagged $B \to e/\mu\ \nu\ \gamma$ (NEW RESULT)
- Semileptonic tagged $B \to K^{(*)}\ \nu\ \nu$

B → l ν decays in the SM

$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$



Helicity suppression

Experimental sensitivity to f_B assuming V_{ub}

- Mediated by the W boson
- μν and eν rare because of helicity suppression (~10^{-7} e, ~10^{-11} mu)
- B meson decay constant f_B can be measured assuming V_{ub}
- V_{ub} (exp. + theory) and f_B (theory) uncertainties dominate the SM expectation uncertainty:

  Using f_B = 190 ± 13 MeV* and V_{ub} = (4.32 ± 0.16 ± 0.29) x 10^{-3} **

  BF_{SM} (B→τν) = (1.20 ± 0.25) x 10^{-4}

*HPQCD collaboration arXiv:0902.1815v2

**Heavy Flavor Averaging Working Group 2008

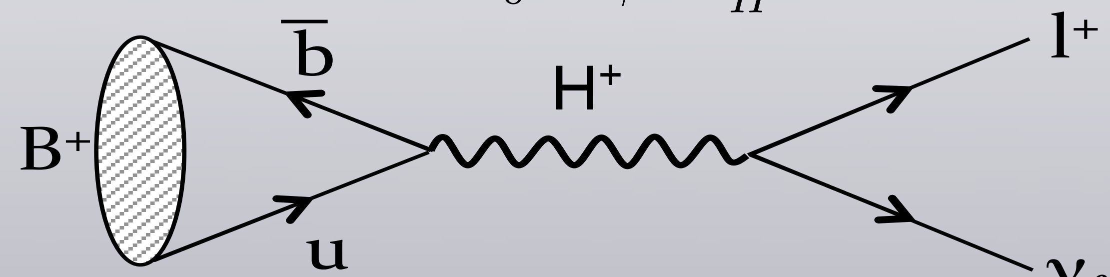
New Physics with purely leptonic decays

$$\mathcal{B}(B \to l\nu)_{2HDM} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2$$

W. S. Hou, Phys. Rev. D 48 (1993) 2342.

$$\mathcal{B}(B \to l\nu)_{SUSY} = \mathcal{B}(B \to l\nu)_{SM} \times (1 - \frac{tan^2\beta}{1 + \epsilon_0 tan\beta} \frac{m_B^2}{m_H^2})^2$$

A.G. Akeroyd and S.Recksiegel J.Phys.G29:2311-2317,2003



- Additional tree level contribution from a charged Higgs
- Branching fraction theoretical expression depends on NP model
- $B \to \tau\nu$ measurement already allows 90% exclusion plot in the $M_H \times \tan\beta$ plane

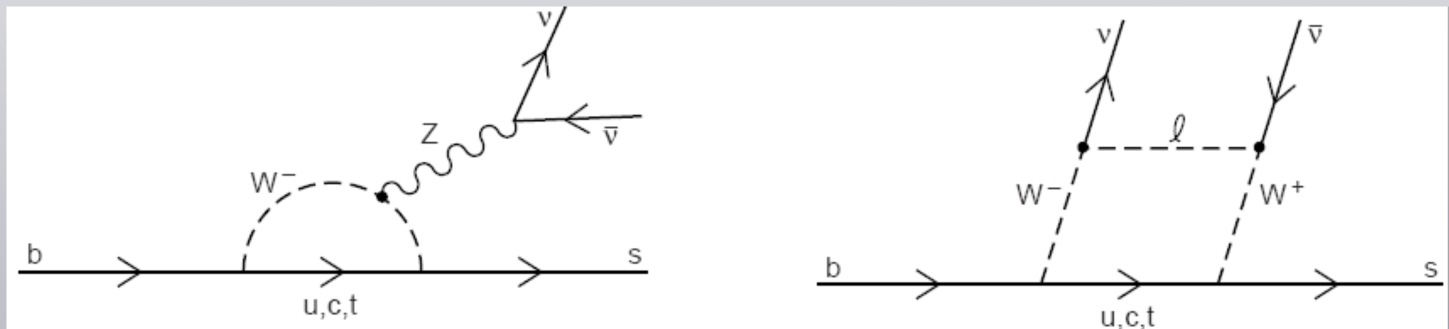
- Comparing different leptonic final states may be interesting for new physics

$$R^{\tau\mu} = \frac{\Gamma(B \to \mu\nu)}{\Gamma(B \to \tau\nu)} \qquad R^{\tau e} = \frac{\Gamma(B \to e\nu)}{\Gamma(B \to \tau\nu)}$$

  - Non minimal FV models predictions: $R_{\tau\mu} \sim 10\% \, R_{\tau\mu, SM}$ $\quad R_{\tau e} \sim 10^3 \, R_{\tau e, SM}$
  - Out of reach for present B factories; golden channel for super flavor factory

$B \to K^{(*)} \nu \nu$ theoretical overview

- SM: the process requires at least one-loop diagram via FCNC

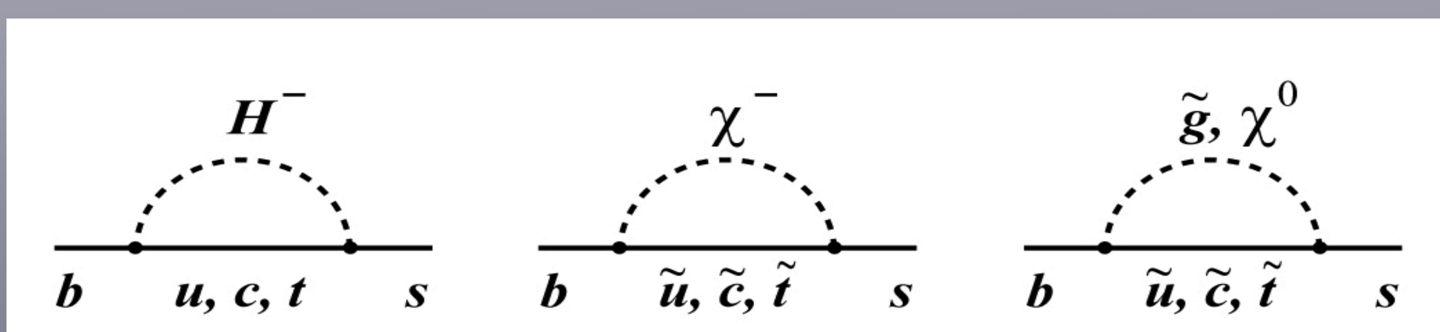


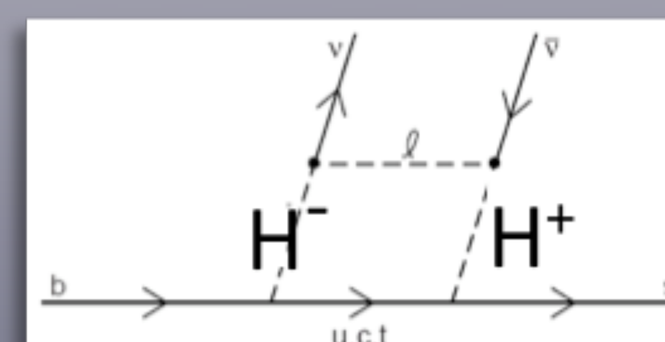
$BR_{SM}(B \to K^{*}\nu\nu) = (6.8^{+1.0}_{-1.1}) \times 10^{-6}$

$BR_{SM}(B \to K\nu\nu) = (4.5 \pm 0.7) \times 10^{-6}$

G.Altmannshofer et al. arXiv:0902.0160

- NP: add particles to the loop diagrams → enhancement of a factor up to 10



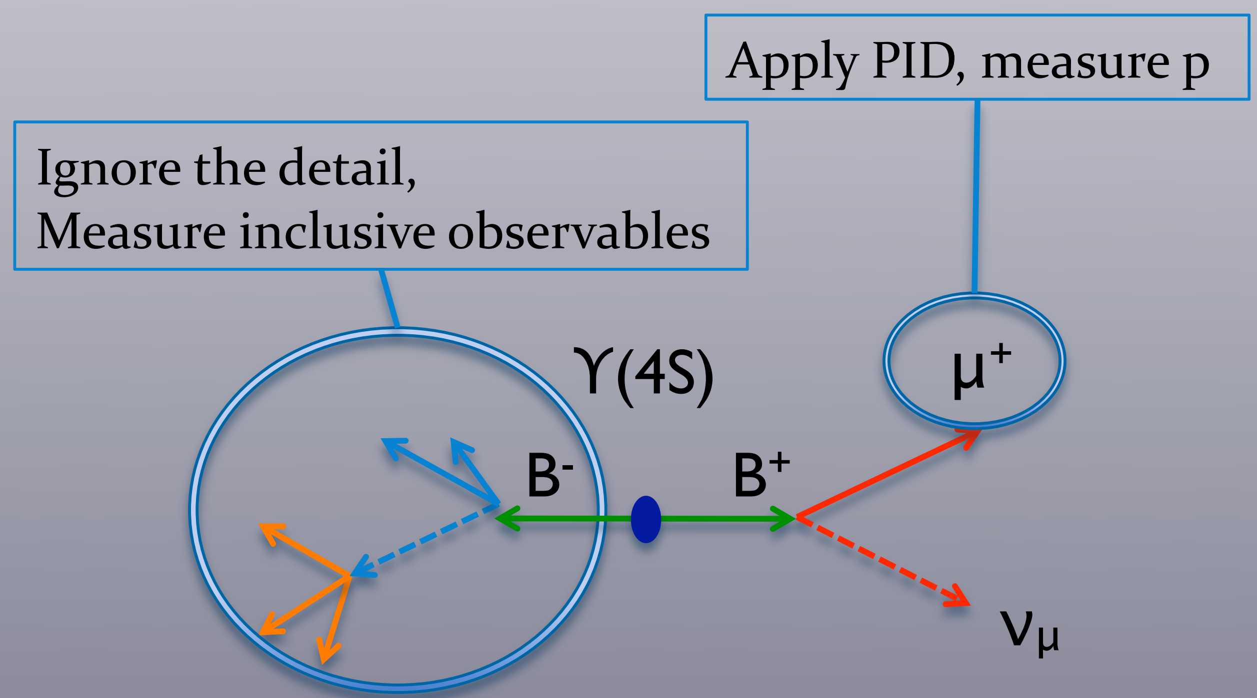


Untagged B → e/μ ν: experimental techniques

Phys. Rev. D 79,091101 (2009)
468 x 10^6 B pairs

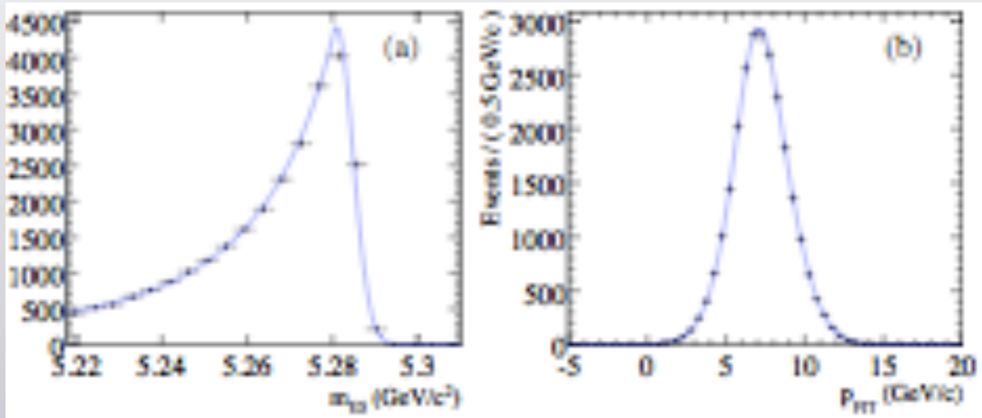
- At ϒ(4S) a pair of B mesons is produced
- SM prediction: $B \to e\nu \sim 10^{-7}$ and $B \to \mu\nu \sim 10^{-11}$
- Strong experimental signature: monochromatic lepton in the rest B frame
  (distribution is smeared in the CM frame)
- Inclusive approach on the rest of the event
- High efficiency but high background

- Identify lepton candidate applying PID requirements (max one lepton required)
- Form a total 4-momentum from the rest of the event (only PID track but no intermediate particle reconstruction)
- Kinematical and topological variables combined in Fisher discriminant to suppress background



Untagged B → e/μ ν: results

B → eν signal MC

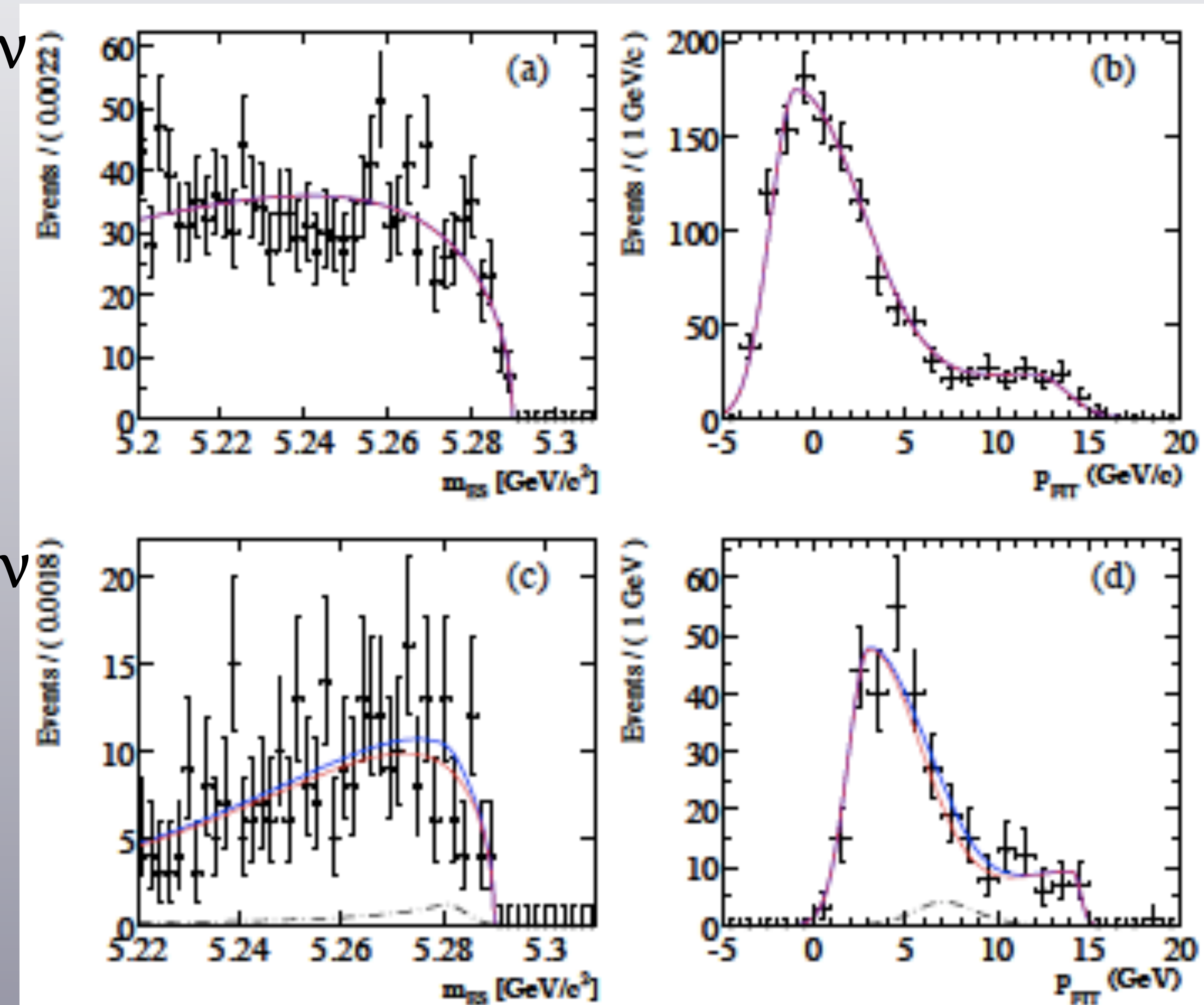


m_{ES} p_{fit}

Phys. Rev. D 79,091101 (2009)

B → μν

B → eν



- Extended Maximum Likelihood fit with 2 variables:
  - m_{ES} using the inclusive B

$$m_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$

  - p_{FIT}, output of Fisher discriminant

	B → eν	B → μν
Signal efficiency	(4.7 ± 0.2) %	(6.1 ± 0.2) %
Fitted signal yield	17.9 ± 17.6	1.4 ± 17.2

BF(B → eν) < 1.9 × 10^{-6}
BF(B → μν) < 1.0 × 10^{-6}
@ 90% C.L.

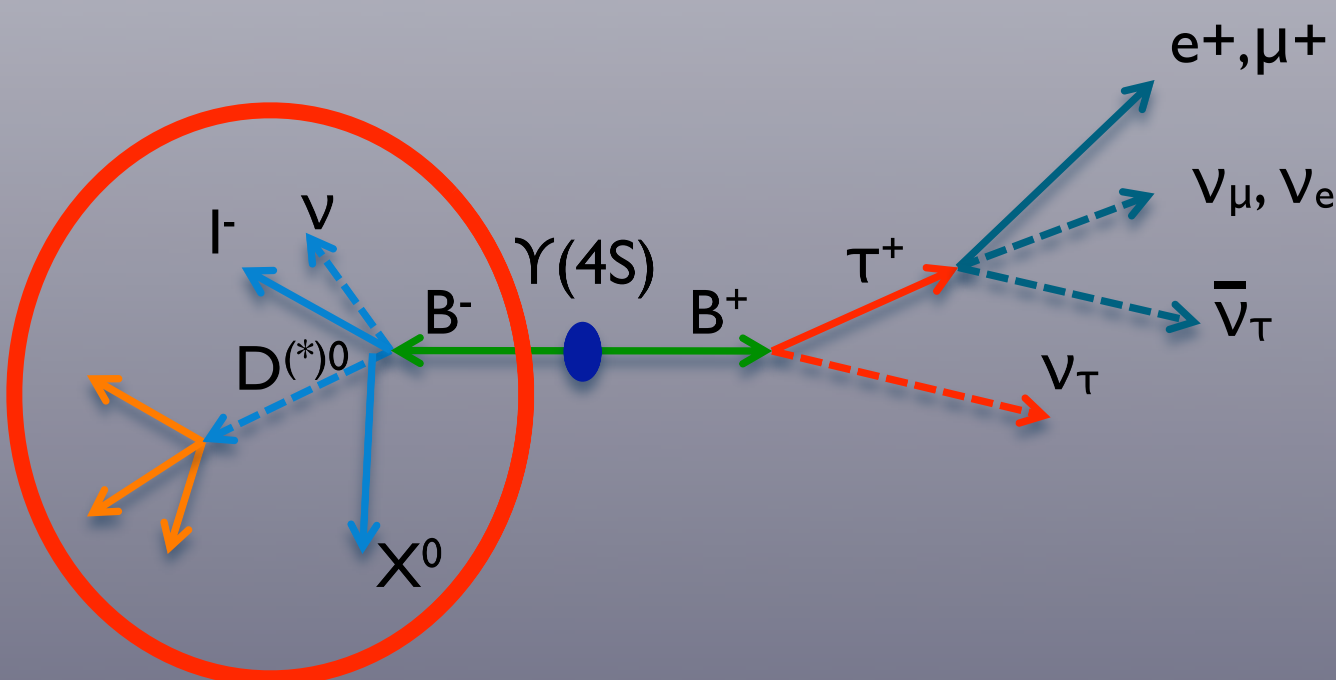
Tagged B: experimental techniques

- Background rejection improved reconstructing the B_{TAG}
- Two kind of tags exploited

Semileptonic decays

+ Higher tag efficiency (~ 1.5%)

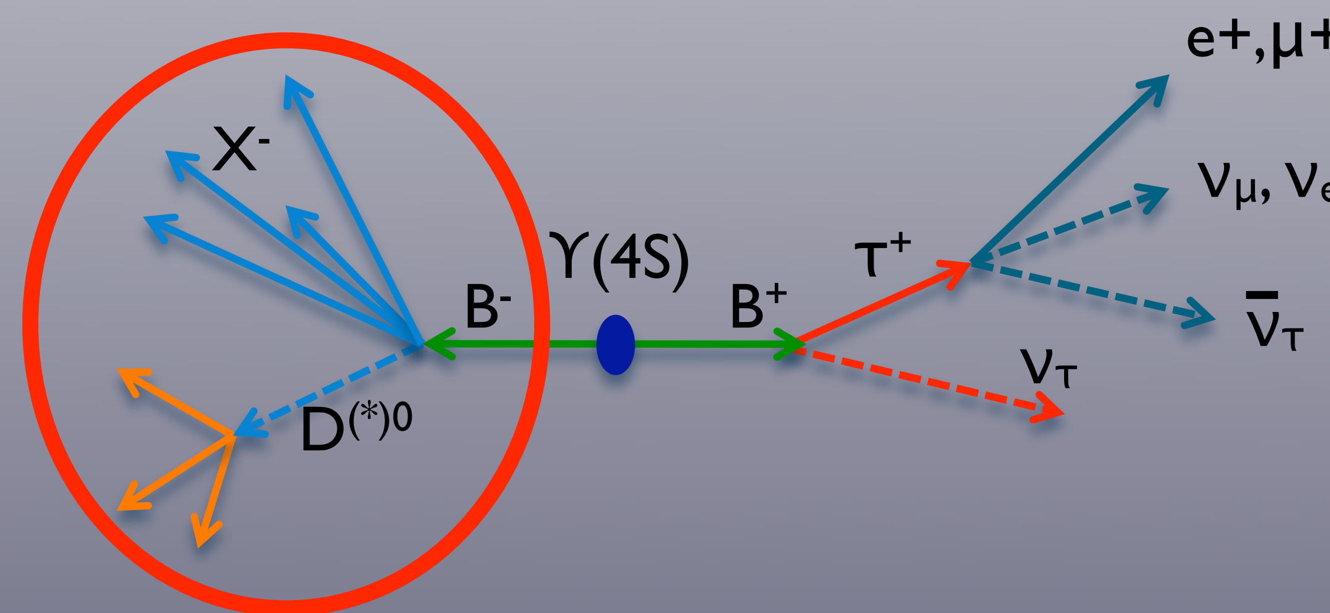
- More background, B momentum unmeasured



Hadronic decays

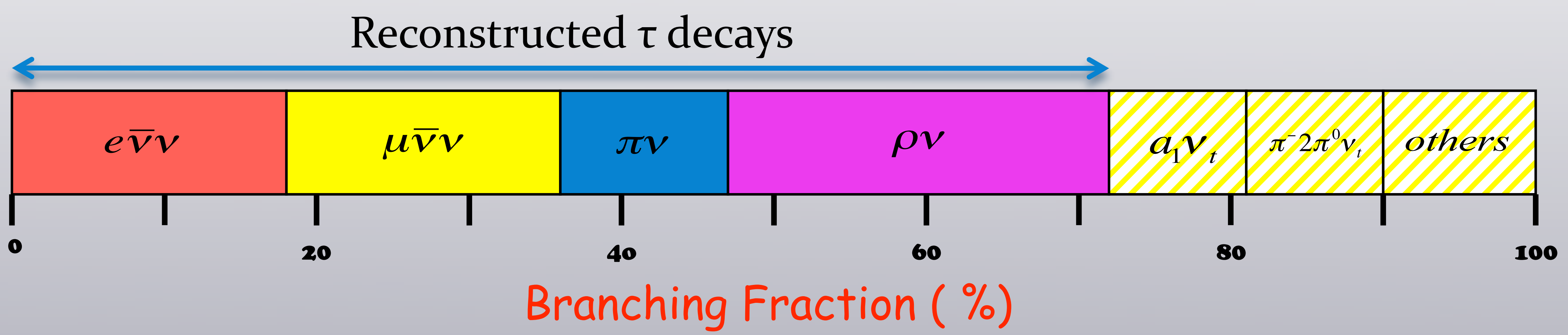
+ Cleaner events, B momentum reconstructed (no neutrinos in tag side)

- Smaller tag efficiency (~0.15%)



$B \to \tau \nu$ with semileptonic tags

arXiv:0809,4027
459×10^6 B pairs



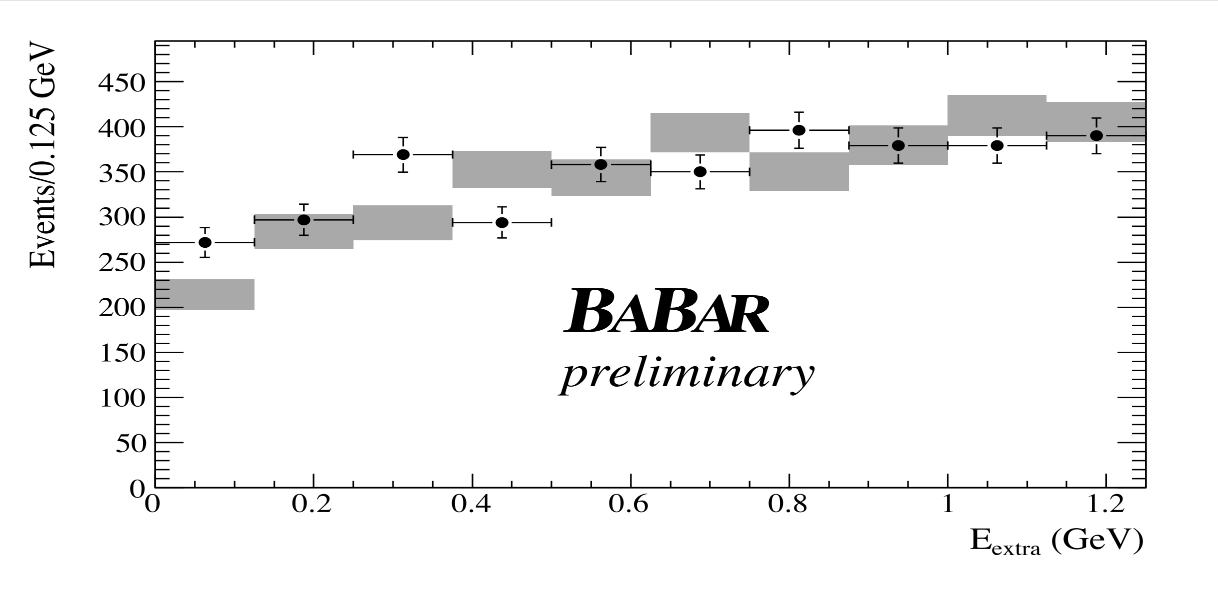
- Separate decay modes using PID and π^0 reconstruction
- Use event topology and signal kinematics variables to suppress background
- Unassigned objects energy E_{extra} is the most discriminating variable

  (peak at zero for signal)

$B \to \tau\,\nu$ with semileptonic tags

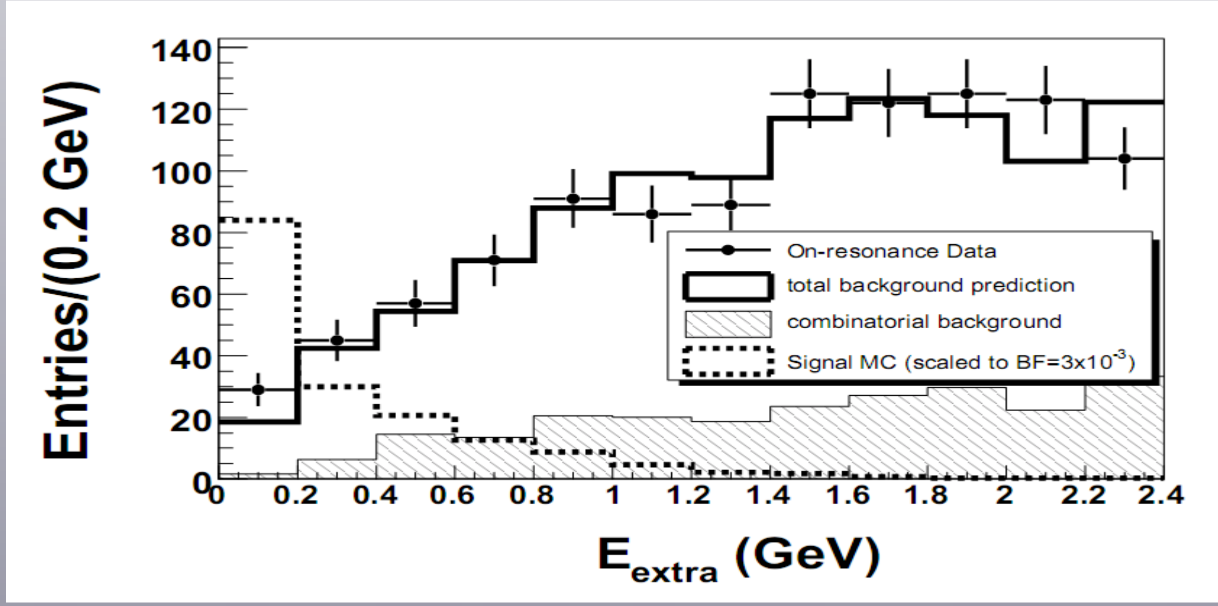
arXiv:0809,4027
459 x 10^6 B pairs

Mode	Expected BKG	Observed	Eff. (x 10^{-4})
$\tau \to e\nu\nu$	91 ± 13	148	3.08 ± 0.14
$\tau \to \mu\nu\nu$	137 ± 10	148	2.28 ± 0.11
$\tau \to \pi\nu$	233 ± 19	243	3.89 ± 0.15
$\tau \to \pi\pi\nu$	59 ± 9	71	1.30 ± 0.07
$B \to \tau\nu$	521 ± 31	610	10.54 ± 0.41



Semileptonic tag

BF $(B \to \tau\nu) = (1.8 \pm 0.8 \pm 0.1) \times 10^{-4}$



Hadronic tag

BF $(B \to \tau\nu) = (1.8 \pm 0.9 \pm 0.4 \pm 0.2) \times 10^{-4}$

Phys. Rev. D 77,011107 (2008) 383 x 10^6 B pairs

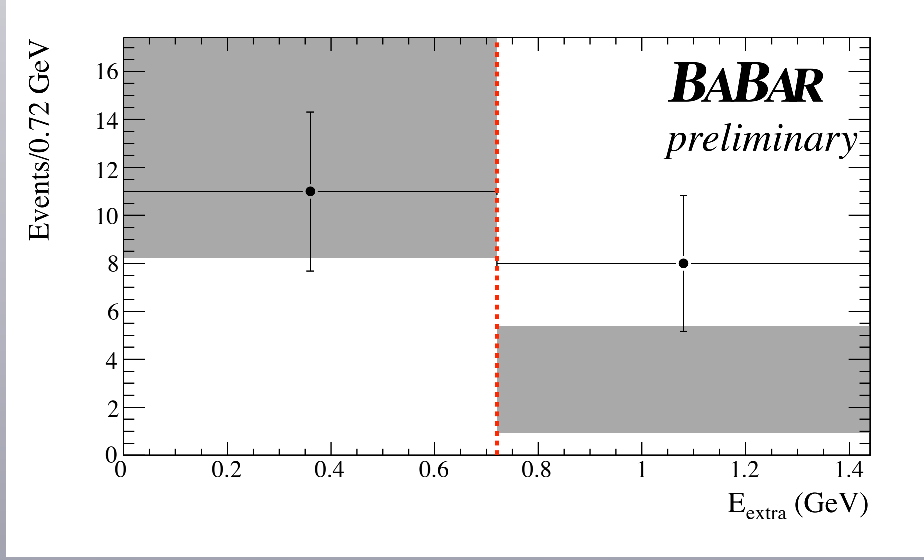
Combined hadronic and semileptonic

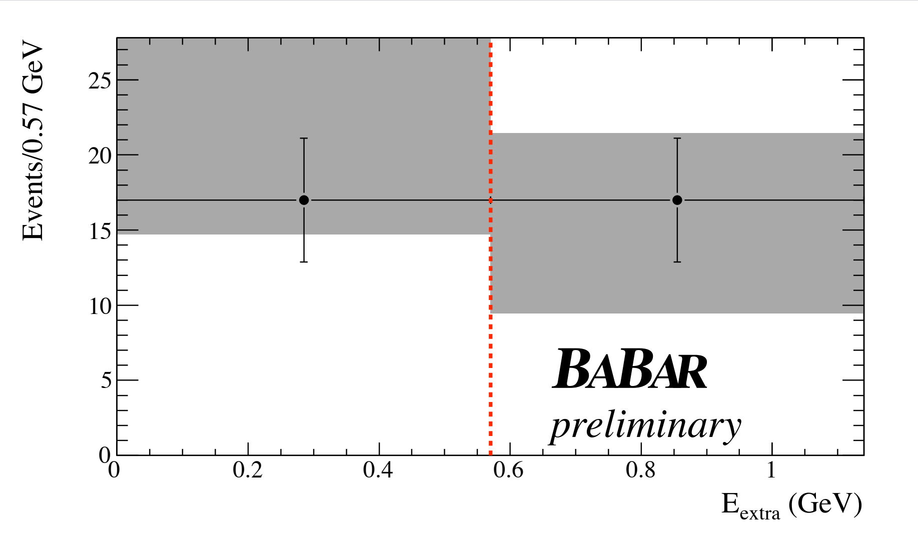
BF $(B \to \tau\nu) = (1.8 \pm 0.6) \times 10^{-4}$

$B \to e/\mu\ \nu$ with semileptonic tags

arXiv:0809,4027
459×10^6 B pairs

- The tag B momentum is not univocally determined.
- The lepton momentum is boosted to the rest B frame using the average value of the tag B momentum
- Signal is identified requiring $p^* > 2.52\ (2.45)$ GeV for electrons (muons)





Mode	Expected	Observed	Eff. (x 10^{-4})	UL 90% CL
$B \to e\nu$	24 ± 11	17	36.9 ± 1.5	7.7×10^{-6}
$B \to \mu\nu$	15 ± 10	11	27.1 ± 1.5	11×10^{-6}

B → lνγ with hadronic tags

Submitted to PRL; arXiv 0907,1689
465 x 10^6 B pairs

- Not helicity suppressed, extra α_{EM} in the BF

$$\frac{d\mathcal{B}}{dE_\gamma} = \frac{\alpha_{EM} G_F^2 |V_{ub}|^2}{48\pi^2} m_B^4 [f_A^2(E_\gamma) + f_V^2(E_\gamma)](1 - 2E_\gamma/m_B)(2E_\gamma/m_B)^3$$

- Form factors model dependent

  HQET to leading order: $f_A = f_V$

  Other models suggest $f_A = 0$

- Correlations with the photon kinematics must be avoided to minimize model dependence; no requirement on photon or lepton momenta

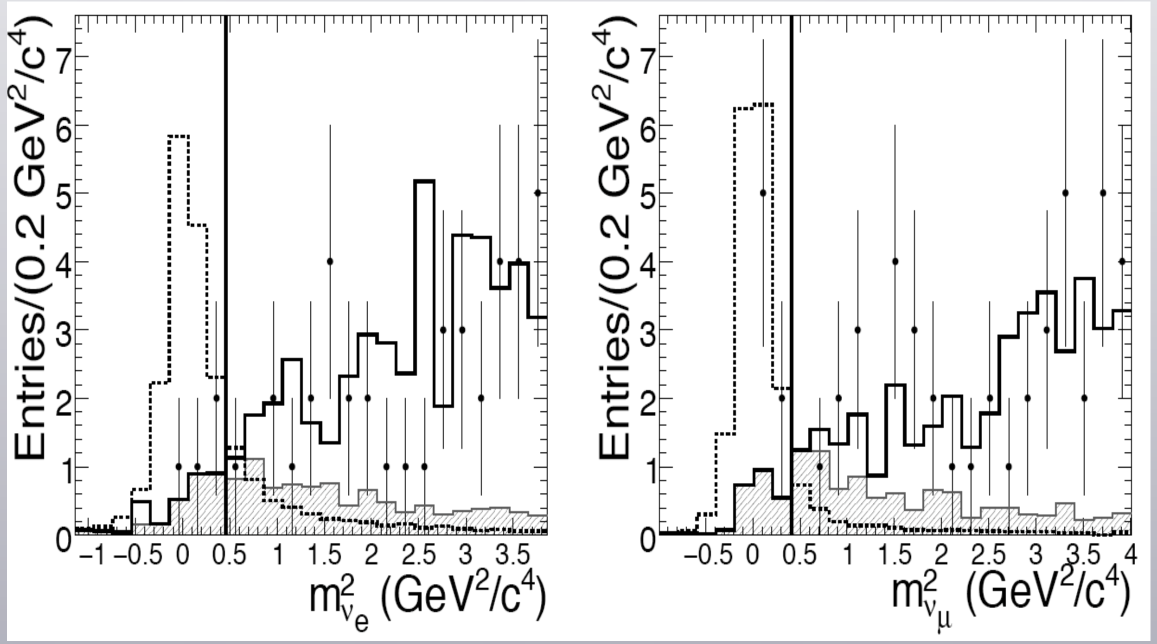
- Combinatorial background reduced by event topology
  - likelihood ratio with 5 discriminating observables
- Selection requirement in the recoil of the tag B include
  - Exactly 1 opposite signed charged track + PID requirements on the signal track
  - The most energetic neutral cluster is the signal candidate
  - Missing momentum in detector acceptance + π^0,η, ω veto on $\gamma\gamma$ and $\pi^0\gamma$
- Residual backgrounds:
  - Incorrectly reconstructed B tags estimated from data in m_{ES} sideband
  - Correctly reconstructed semileptonic B decays estimated from dedicated MC simulation
- Signal box defined by:
  - 5.26 GeV < m_{ES} < 5.29 GeV , M_{miss} < 0.5 GeV^2

$B \to l\nu\gamma$ with hadronic tags results

Submitted to PRL; arXiv 0907,1689
465×10^6 B pairs

Cut and count analysis and frequentist (FC) estimation of the U.L. on the branching fraction:

	$B \to e\nu\gamma$	$B \to \mu\nu\gamma$
Expected bkg	$2.7 \pm 0.4 \pm 0.4$	$3.4 \pm 0.7 \pm 0.7$
Observed events	4	7
Signal efficiency	$(7.8 \pm 0.1 \pm 0.3) \times 10^{-4}$	$(8.1 \pm 0.1 \pm 0.3) \times 10^{-4}$
BF 90 % CL	$< 17 \times 10^{-6}$	$< 26 \times 10^{-6}$
	$< 15 \times 10^{-6}$	



Model dependent limits

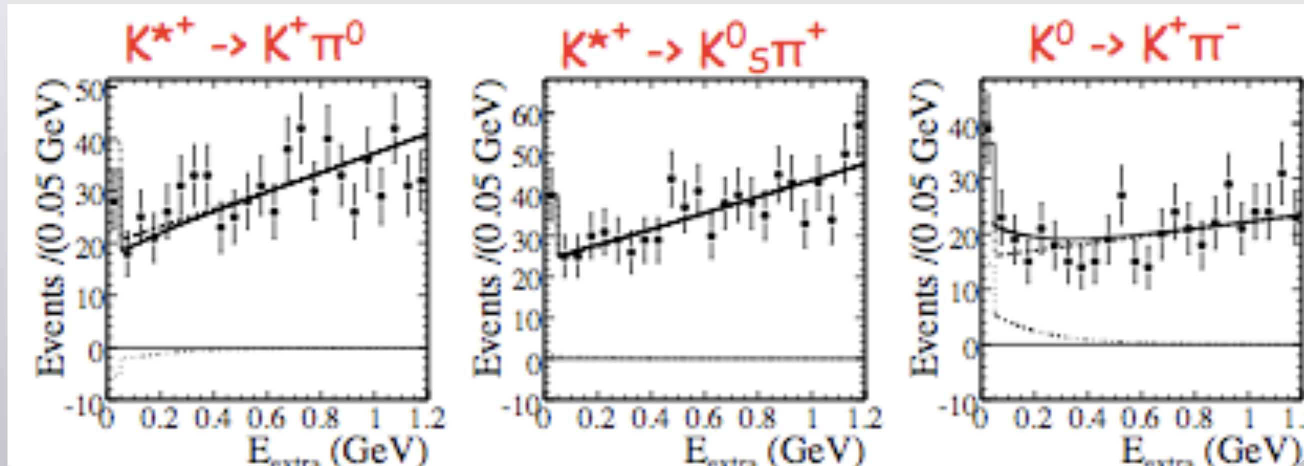
Requiring a cut on the angle between the lepton and the photon and on the angle between the photon and the neutrino, the signal is searched assuming the $f_A=f_V$ and the $f_A=0$ hypothesys

mode	$f_A = f_V$ hypothesis			$f_A = 0$ hypothesis		
	Expected	Observed	BF 90 % CL	Expected	Observed	BF 90 % CL
$B \to e\nu\gamma$	0.6 ± 0.1	0	$< 8.4 \times 10^{-6}$	1.2 ± 0.4	3	$< 29 \times 10^{-6}$
$B \to \mu\nu\gamma$	1.0 ± 0.4	0	$< 6.7 \times 10^{-6}$	1.5 ± 0.5	2	$< 22 \times 10^{-6}$
combined			$< 3.0 \times 10^{-6}$			$< 18 \times 10^{-6}$

$B \to K^{(*)}\nu\nu$ analysis strategy and results

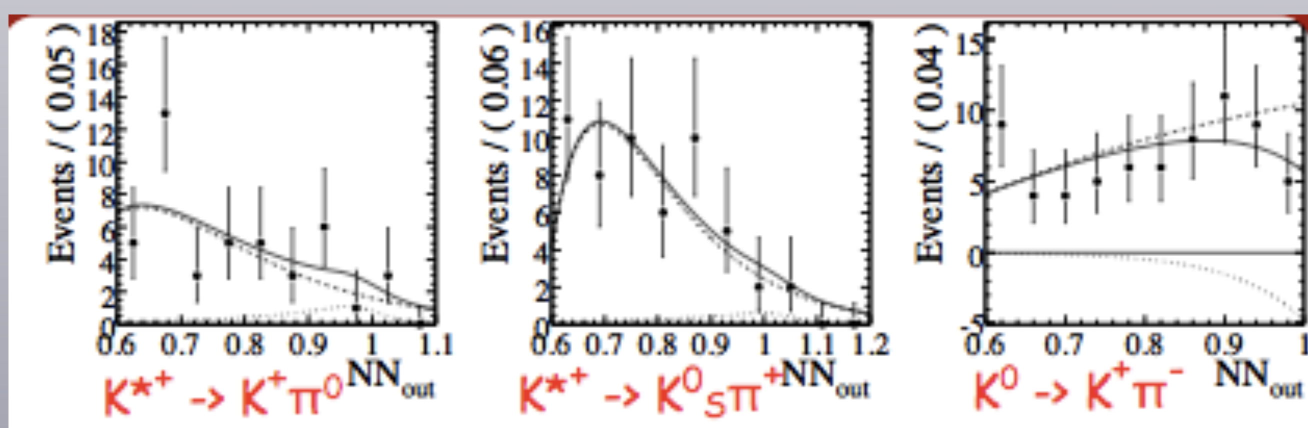
Phys. Rev. D 78,072007 (2008)

Combined results from the semileptonic and hadronic recoil analyses



Semileptonic tag

E_{extra}



Hadronic tag

NN output

- BaBar 454 M BB
- No cuts on K^* kinematics
- First completely model independent analysis

UL @ 90%CL	$B^+ \to K^{*+}\nu\nu$	$B^0 \to K^{*0}\nu\nu$
HAD	21×10^{-5}	11×10^{-5}
SL	9×10^{-5}	18×10^{-5}
Combined	8×10^{-5}	12×10^{-5}

351 M BB (preliminary) UL @90%CL	$B^+ \to K^+\nu\nu$
Combined (SL+HAD)	4.2×10^{-5}

Conclusions

- Searches for decays involving leptons:

  test for the SM prediction

  indirect search for NP (no significant NP signal seen so far)

  experimental measurements allow to constraint parameters defining NP

  complementary to direct search of NP at high energy machines

  need more precision and statistics → Super Flavor Factories