# Search for $B \to \tau\nu$ at the BABAR experiment

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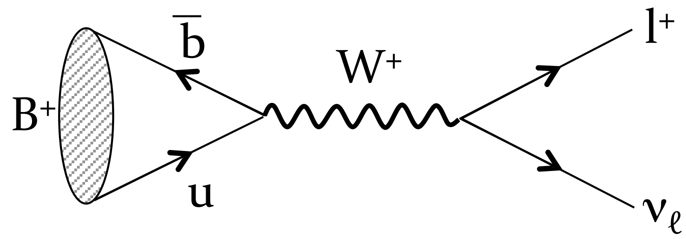
Napoli University and INFN

ICHEP 2010, Paris, 23 July 2010

# $B \to l\,\nu$ decays in the SM




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

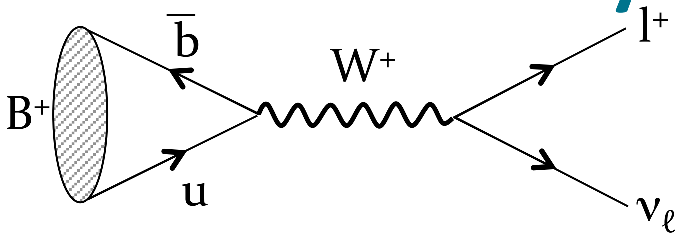
Helicity suppression

Experimental sensitivity to $f_B$ assuming $V_{ub}$

- Can be used to measure the B meson decay constant $f_B$ assuming $V_{ub}$
- Vub (exp.+theo) and $f_B$ (theo) uncertainties dominate the SM expectation uncertainty:
  - Using $f_B$ = 190 ± 13 MeV * and $V_{ub}$ = (3.5 ± 0.4 ) × $10^{-3}$ **
    $BF_{SM}(B \to \tau\nu)$ = (0.80 ± 0.20) × $10^{-4}$

*HPQCD collaboration arXiv:0902.1815v2
** UTFit and CKM fitter collaborations

# $B \to l\,\nu$ decays beyond the SM

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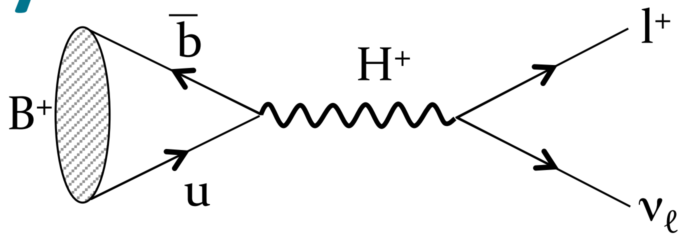



- Additional tree level contribution from a charged Higgs
  - It does not suffer from helicity suppression, but gets the same $m_l$ dependence from Yukawa coupling
  - Branching fraction theoretical expression depends on the NP model

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

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

- $B \to \tau\nu$ measurement already allows 90% exclusion plots in the plane of NP parameters $M_H \times \tan\beta$

# Past Measurements

BABAR Hadronic tags

$\mathcal{B}(B \to \tau\nu) = (1.8^{+0.9}_{-0.8}(\mathrm{stat.}) \pm 0.4 \pm 0.2) \times 10^{-4}$

Phys. Rev. D 77, 011107(R) (2008)

BABAR Semi-leptonic tags

$\mathcal{B}(B \to \tau\nu) = (1.7 \pm 0.8 \pm 0.2) \times 10^{-4}$

Phys. Rev. D 81,051101(R) (2010)

BELLE Hadronic tags

$\mathcal{B}(B \to \tau\nu) = (1.79^{+0.56}_{-0.49}(\mathrm{stat.})^{+0.46}_{-0.51}) \times 10^{-4}$

Phys. Rev. Lett. 97, 261802 (2006)

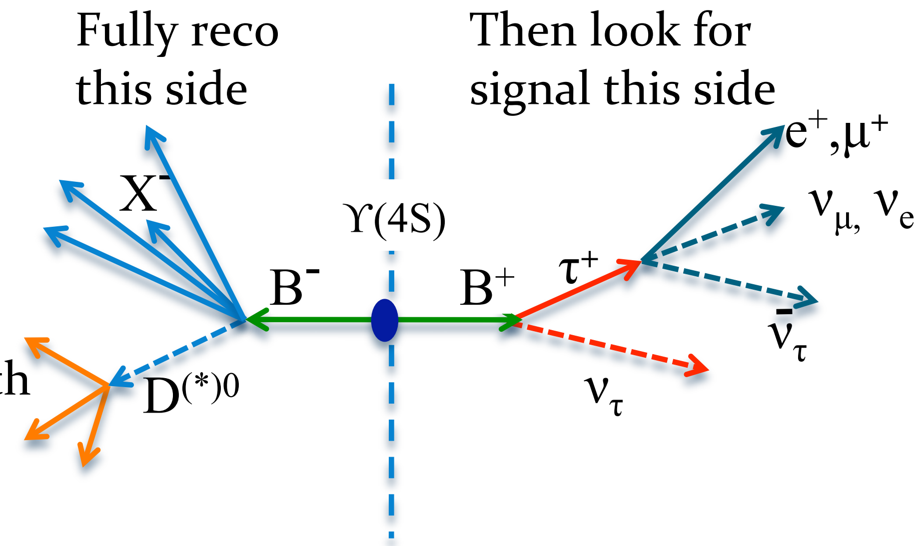
BELLE Semi-leptonic tags

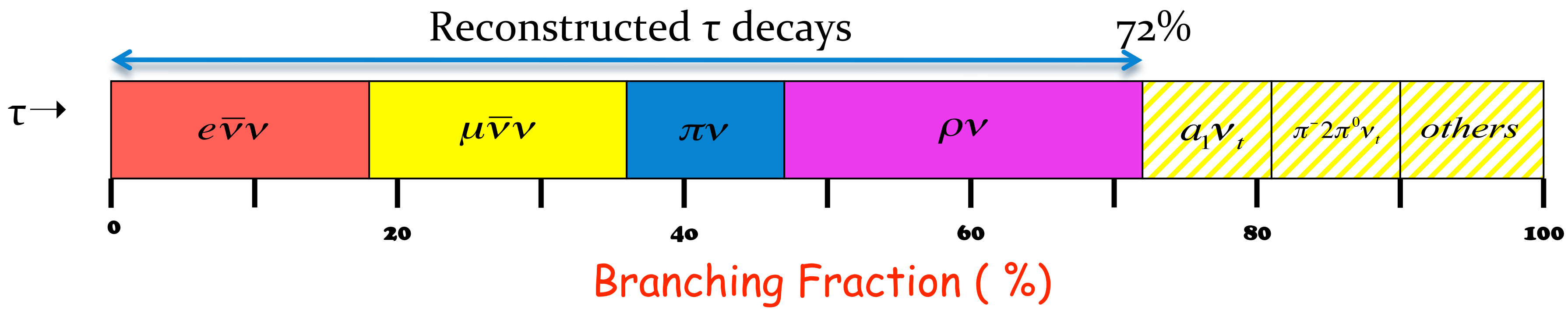
$\mathcal{B}(B \to \tau\nu) = (1.54^{+0.38}_{-0.37}(\mathrm{stat.})^{+0.29}_{-0.31}) \times 10^{-4}$

arXiv:1006.4201[hep-ex]

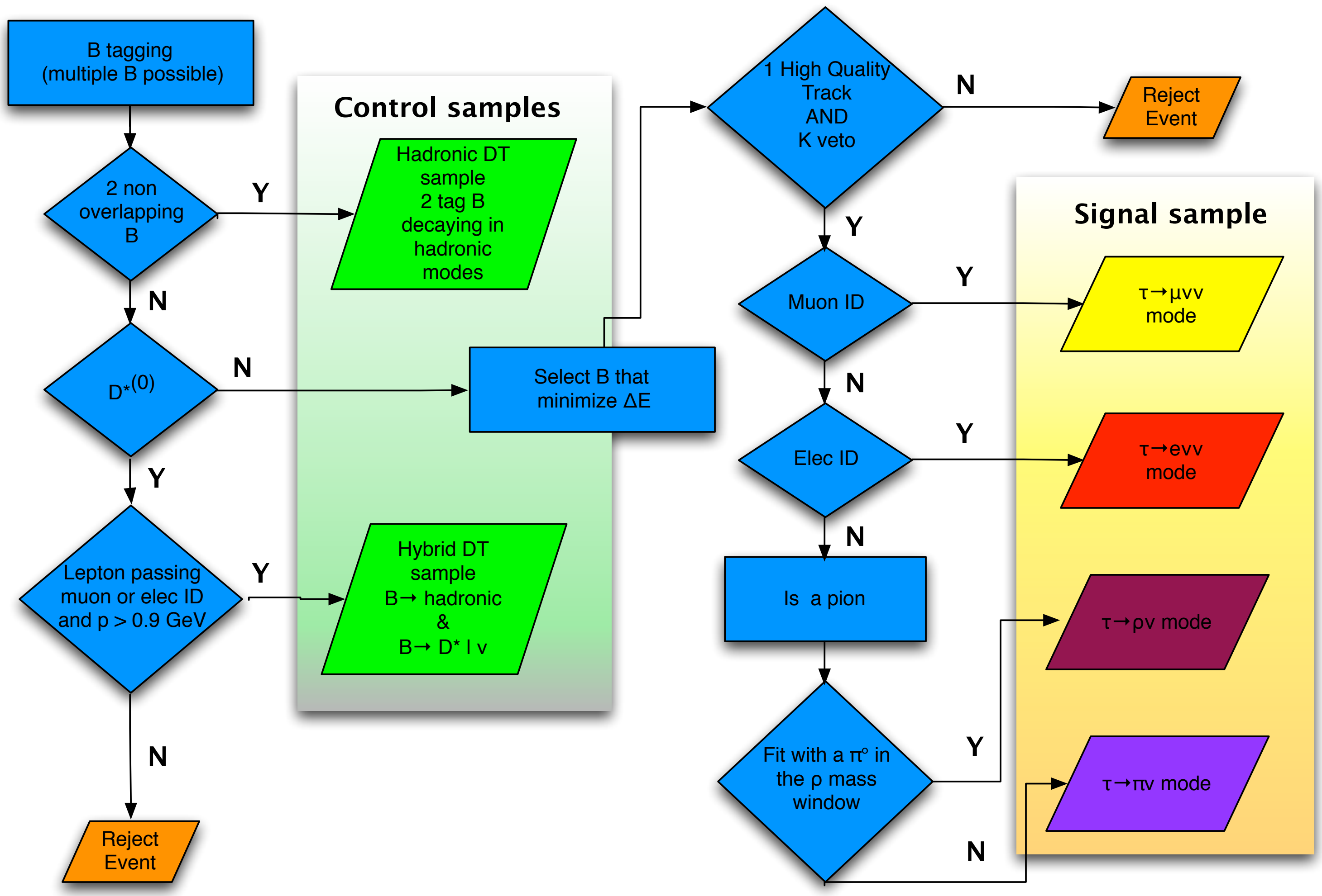
# Hadronic tags

- Weak signal signature
  - Decay with missing momentum (many neutrinos in the final state)
  - Indirect detection of a τ in final state
- background rejection improved fully reconstructing the companion B (tag) with charmed hadronic decays
- Look for signal in the rest of the event
  - Expect to find nothing more than a single charged track and no activity in the calorimeter



# Data Samples

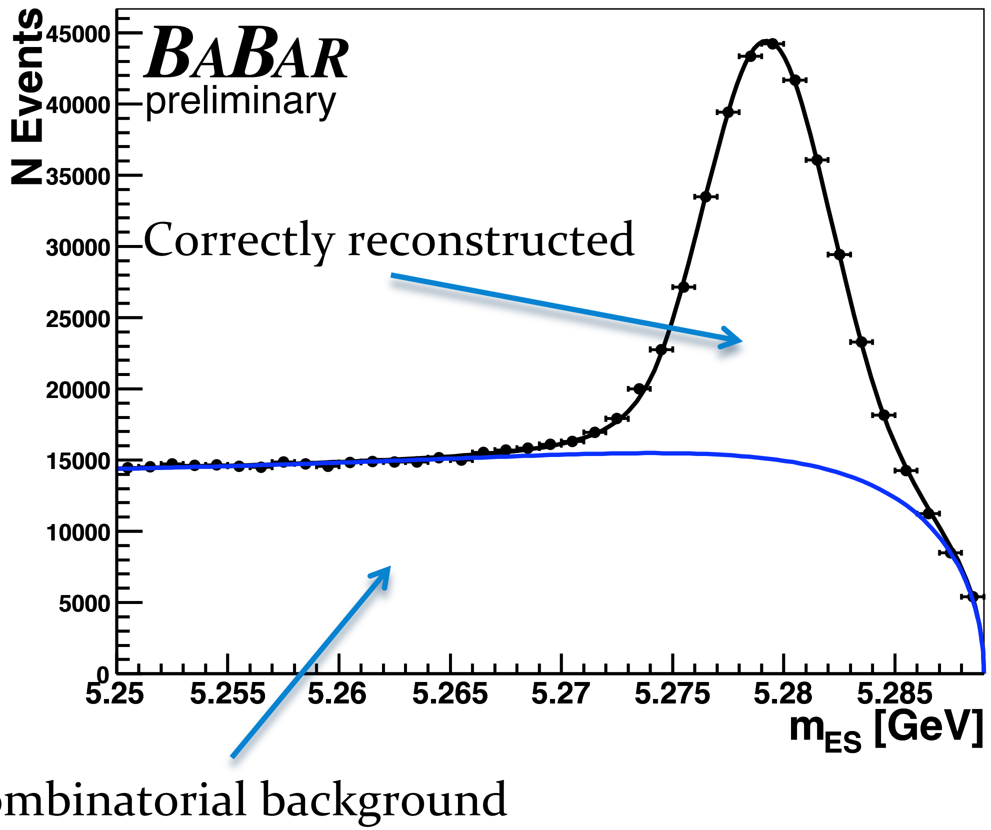


# Hadronic tags

$$\epsilon_{sig,data} = R \times \epsilon_{sig,MC}$$

$$R = \frac{\epsilon_{B^+B^-,data}}{\epsilon_{B^+B^-,MC}}$$

- B -> D(*) X and B -> J/ψ X with single mode purity P > 10% (optimized)
- In case of multiple B candidates select the one with smallest |ΔE|
- Fit with a Crystal Ball (correctly reconstructed B) + 2 Argus (combinatorial)



# Signal Selection

- Combinatorial and continuum background reduction combine 3 variables in a likelihood ratio
  - D momentum, Cos ϑ thrust, Thrust magnitude
- Exploit kinematics in the signal side
  - Requirement on CMS momentum for 1 prong modes
  - Combine 4 variables in a Likelihood ratio for $\tau \rightarrow \pi\pi^0$
- Most discriminating variable residual energy in the calorimeter ($E_{extra}$)
  - Defined as the total energy of clusters passing a minimum energy requirement of 60 MeV
  - Used in a maximum likelihood fit to determine the branching fraction
- Optimized aiming at the smallest statistical + systematic uncertainty
  - By means of toy MC experiments

# Fit strategy

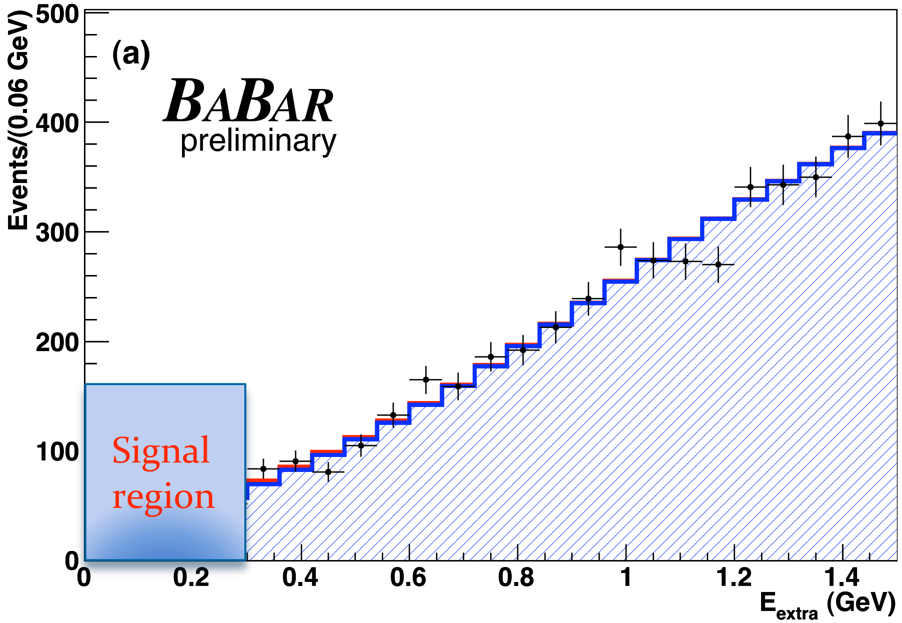
- Maximum likelihood fit to $E_{extra}$ distribution
- Simultaneously on the four τ decay modes

$$\mathcal{L}_k = e^{-(n_{s,k}+n_{b,k})} \prod_{i=1}^{N_k} \left\{ n_{s,k}\mathcal{P}_k^s(E_{i,k}) + n_{b,k}\mathcal{P}_k^b(E_{i,k}) \right\}$$

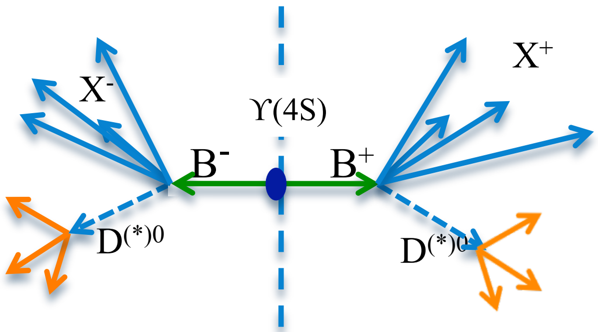
$$n_{s,k} = N_{B\overline{B}} \times \epsilon_k \times BF$$

Signal PDF taken from signal MC and corrected for data/MC disagreements

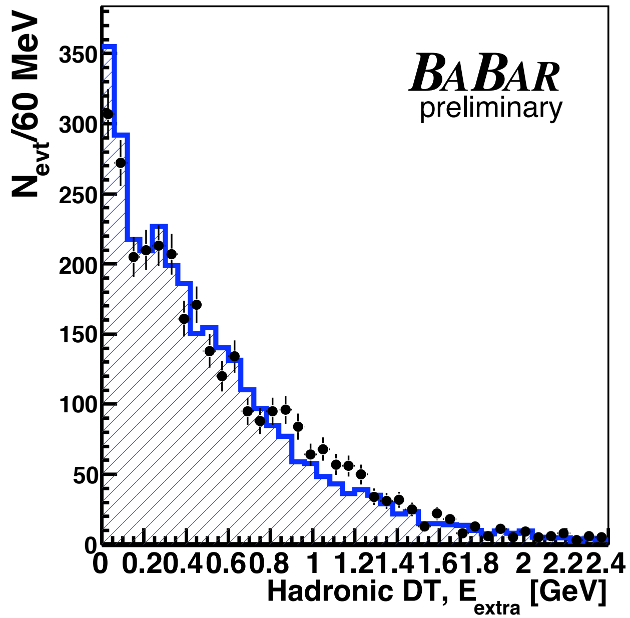
Background PDF from
  data SB (comb. Background)
  B+B- MC (peak. comp. only)

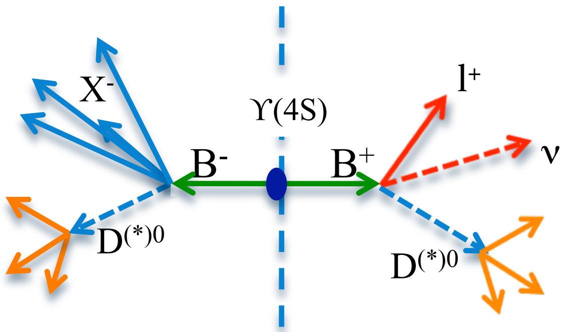


# $E_{extra}$ validation on double tags

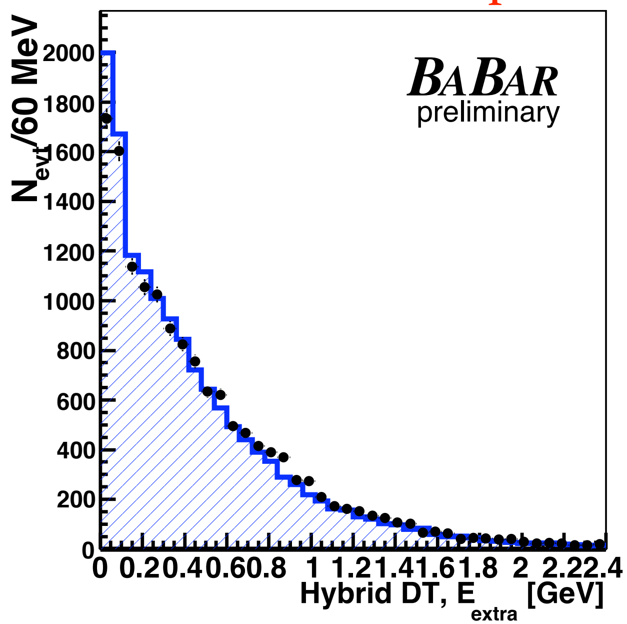



Hadronic Hadronic




Hadronic Semi-leptonic

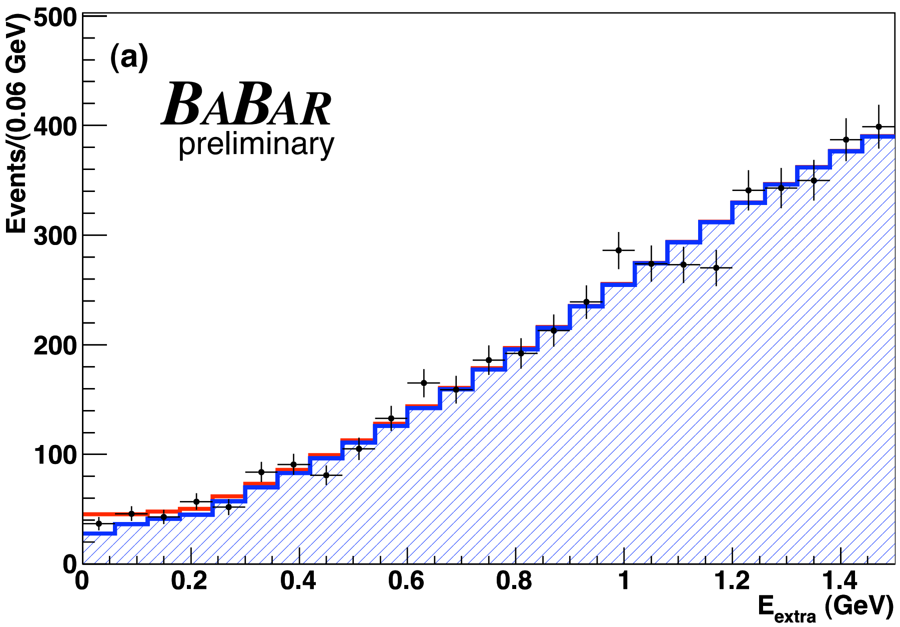


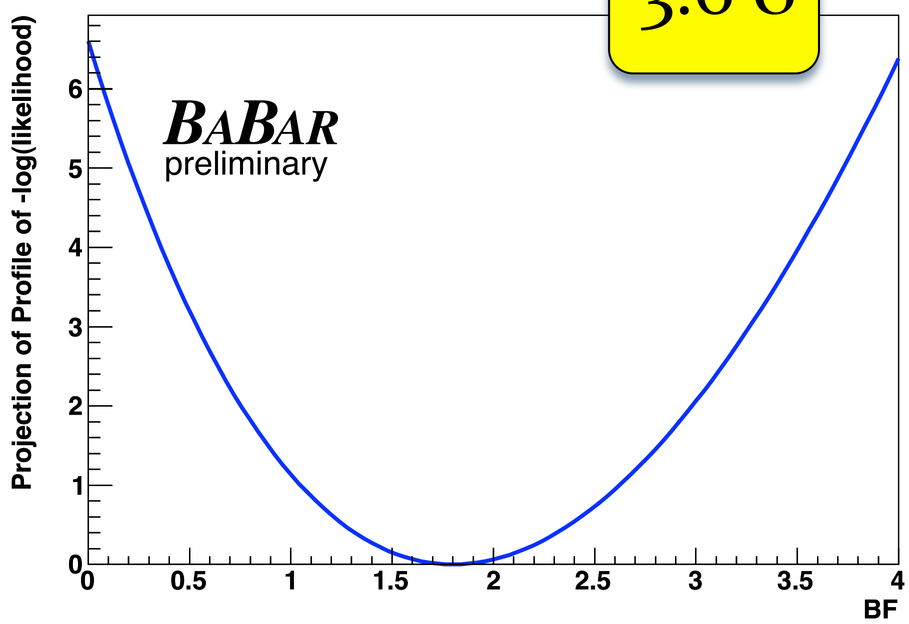
# Fit results

- Significant excess of events at low $E_{extra}$

$$\mathcal{B}(B \rightarrow \tau\nu) = 1.80^{+0.57}_{-0.54} \times 10^{-4}$$

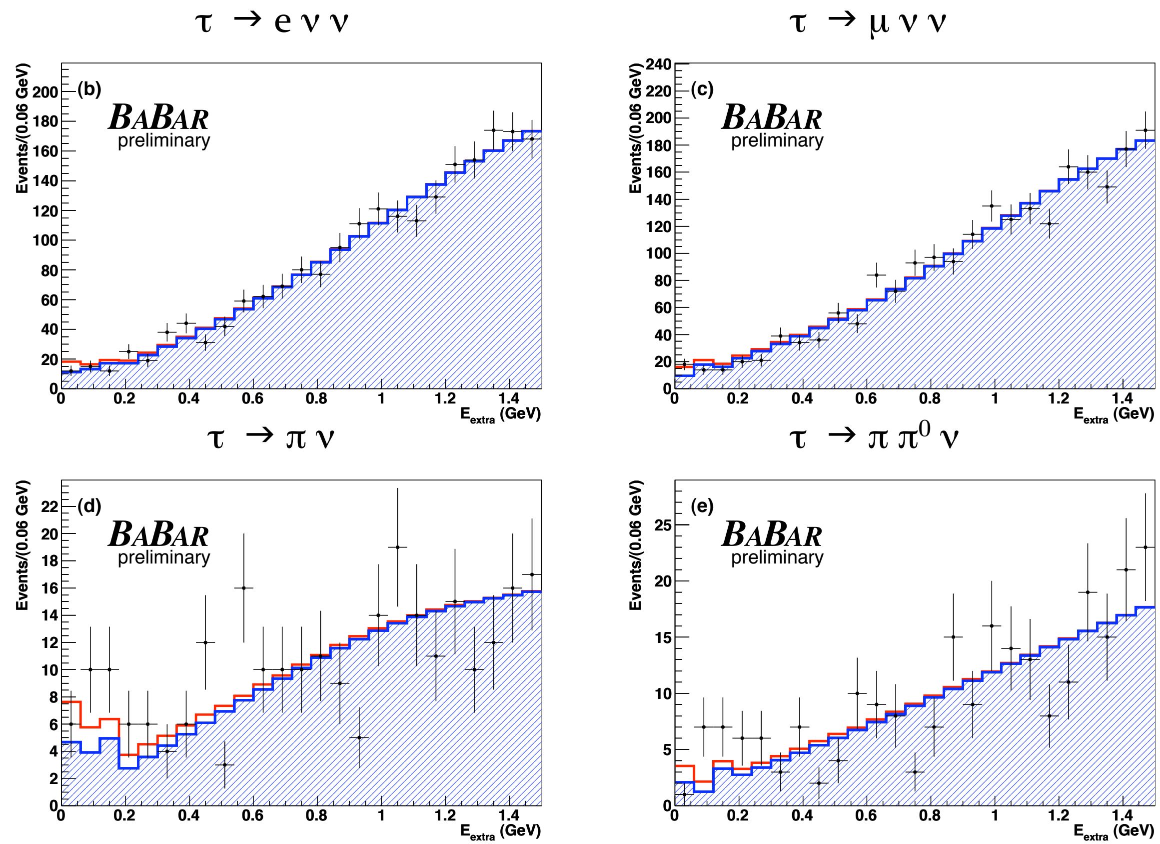
3.6 σ



# Simultaneous fit projections

| Decay Mode | $\epsilon \times 10^{-4}$ | BF $(\times 10^{-4})$ | Sign. $\sigma$ |
|---|---|---|---|
| $\tau^+ \to e^+ \nu \bar{\nu}$ | 2.73 | $0.39^{+0.89}_{-0.79}$ | 0.5 |
| $\tau^+ \to \mu^+ \nu \bar{\nu}$ | 2.92 | $1.23^{+0.89}_{-0.80}$ | 1.6 |
| $\tau^+ \to \pi^+ \nu$ | 1.55 | $4.0^{+1.5}_{-1.3}$ | 3.3 |
| $\tau^+ \to \rho^+ \nu$ | 0.85 | $4.3^{+2.2}_{-1.9}$ | 2.6 |
| combined | 8.05 | $1.80^{+0.57}_{-0.54}$ | 3.6 |



# Systematic uncertainties

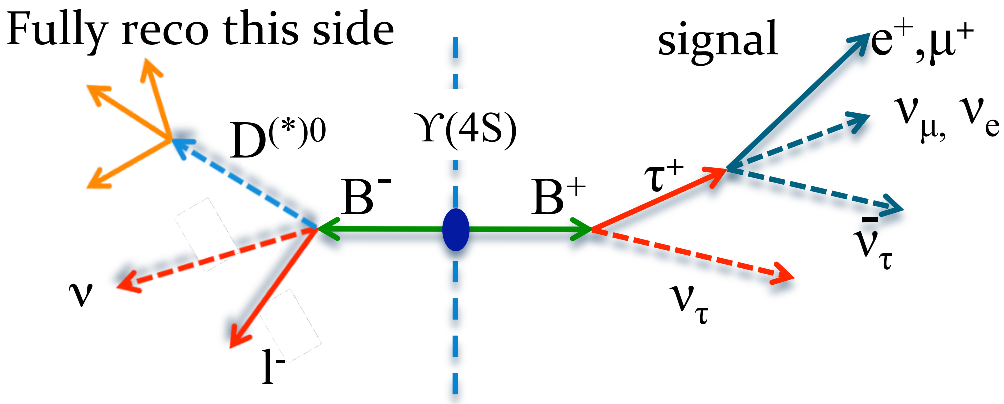
| Source of systematics | BF uncertainty (%) |
|---|---|
| B counting | 0.5 |
| Tag $B$ efficiency | 5.0 |
| Background PDF | 12 |
| Signal PDF | 1.7 |
| MC statistics | 0.8 |
| Electron identification | 2.6 |
| Muon identification | 4.7 |
| Kaon identification | 0.4 |
| Tracking | 1.4 |
| Total | 14 |

$$\mathcal{B}(B \to \tau\nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$$

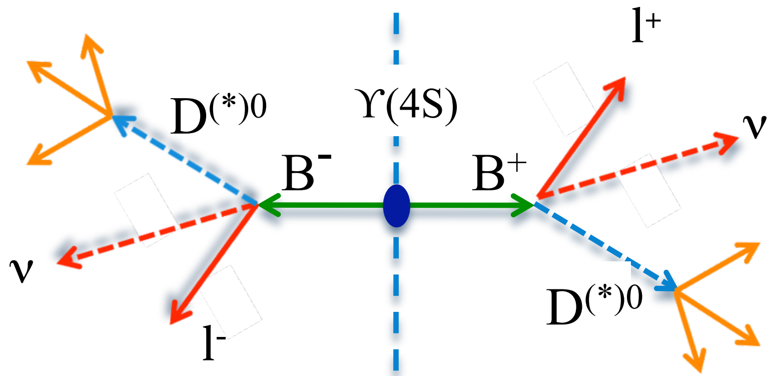
# Analysis with Semi-leptonic tags

- Similar technique with semi-leptonic B tags

Phys. Rev. D 81,051101(R) (2010)

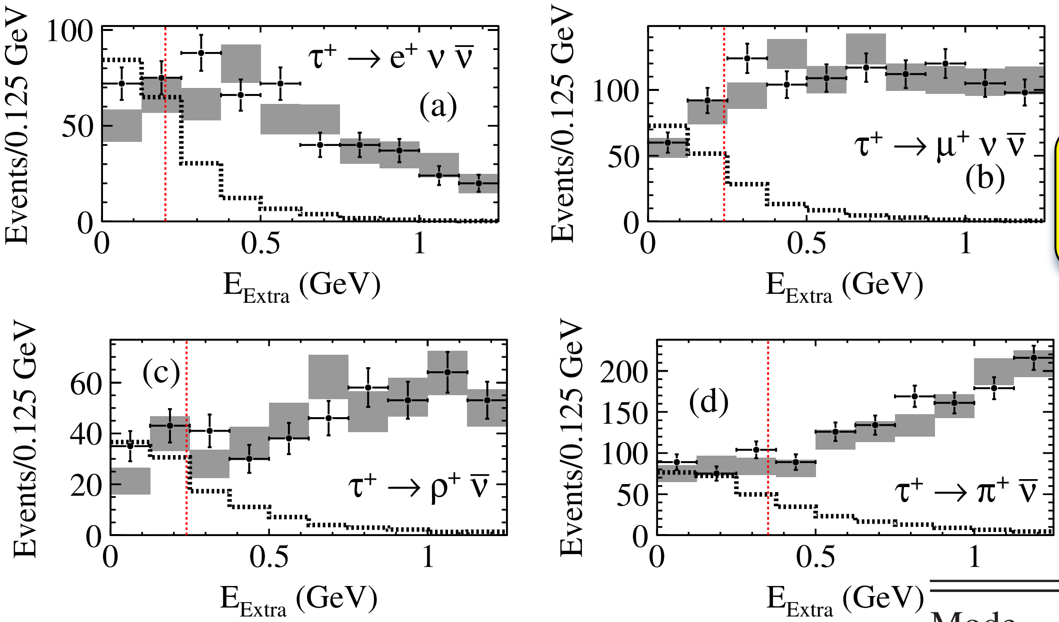



Analysis Sample



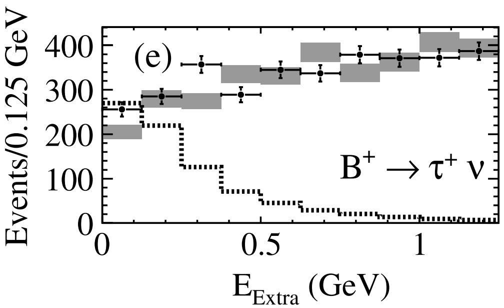

Control Sample

# Results for semi-leptonic tags




$B( B \to \tau\nu ) = (1.7 \pm 0.8 \pm 0.2)\times 10^{-4}$

Excluding null hypothesis at 2.3 σ




| Mode | $\mathcal{N}_{bg}^{data}$ | $N_{obs}$ | Branching fraction ($\times 10^{-4}$) |
|---|---|---|---|
| $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$ | $81 \pm 12$ | 121 | $(3.6 \pm 1.4)$ |
| $\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$ | $135 \pm 13$ | 148 | $(1.3^{+1.8}_{-1.6})$ |
| $\tau^+ \to \rho^+ \bar{\nu}_\tau$ | $59 \pm 9$ | 71 | $(2.1^{+2.0}_{-1.8})$ |
| $\tau^+ \to \pi^+ \bar{\nu}_\tau$ | $234 \pm 19$ | 243 | $(0.6^{+1.4}_{-1.2})$ |
| $B^+ \to \tau^+ \nu_\tau$ | $509 \pm 30$ | 583 | $(1.7 \pm 0.8 \pm 0.2)$ |
| $B^+ \to \mu^+ \nu_\mu$ | $13 \pm 8$ | 12 | $<0.11$ (90% C.L.) |
| $B^+ \to e^+ \nu_e$ | $24 \pm 11$ | 17 | $<0.08$ (90% C.L.) |

# Conclusions

- Updated the B → τν measurement to the full BABAR dataset with hadronic B tags

$$\mathcal{B}(B \to \tau\nu) = (1.80^{+0.57}_{-0.54} \pm 0.26) \times 10^{-4}$$ PRELIMINARY

- Excluding the null hypothesis at the 3.6 σ level
  - Supersedes our previous measurement in Phys. Rev. D 77, 011107(R) (2008)
- Combining with the measurement with semi-leptonic tags we present a single BABAR measurement of

$$\mathcal{B}(B \to \tau\nu) = (1.76 \pm 0.49) \times 10^{-4}$$ PRELIMINARY

# Back up slides

# Selection optimization

- We optimized the selection criteria taking into account statistical + largest systematic uncertainty in signal and background PDF
- Fitting toy experiments generated with nominal probability density functions to estimate the expected statistical uncertainties

| Variable | $\tau^+ \to e^+\nu\bar{\nu}$ | $\tau^+ \to \mu^+\nu\bar{\nu}$ | $\tau^+ \to \pi^+\nu$ | $\tau^+ \to \rho^+\nu$ |
|---|---|---|---|---|
| R2 | $< 0.57$ | $< 0.56$ | $< 0.56$ | $< 0.51$ |
| purity | $> 10\%$ | $> 10\%$ | $> 10\%$ | $> 10\%$ |
| $L_C$ | $> 0.2$ | $> 0$ | $> 0.3$ | $> 0.45$ |
| $p^*_{trk}(\mathrm{GeV}/c)$ | $< 2.1$ | $< 2$ | $> 1.4$ | |
| $L_P$ | | | | $> 0.8$ |

| mode | $e\nu\bar{\nu}(\%)$ | $\mu\nu\bar{\nu}(\%)$ | $\pi\nu(\%)$ | $\rho\nu(\%)$ |
|---|---|---|---|---|
| $e\nu\bar{\nu}$ | **58.1±0.5** | 0.39±0.06 | 0.21±0.04 | 0.01±0.01 |
| $\mu\nu\bar{\nu}$ | 0.02±0.01 | **55.7±0.5** | 1.02±0.09 | 0.04±0.02 |
| $\pi\nu$ | 0.17±0.05 | 2.8±0.2 | **37.1±0.6** | 1.8±0.2 |
| $\rho\nu$ | 0.33±0.04 | 3.2±0.1 | 5.8±0.2 | **9.6±0.2** |
| other | 0.18±0.03 | 1.4±0.1 | 0.74±0.06 | 2.1±0.1 |
| **all $\tau$ dec.:** | **10.5±0.5** | **11.2±0.5** | **6.0±0.6** | **3.2±0.3** |
| **total:** | **30.9±1.0** | | | |