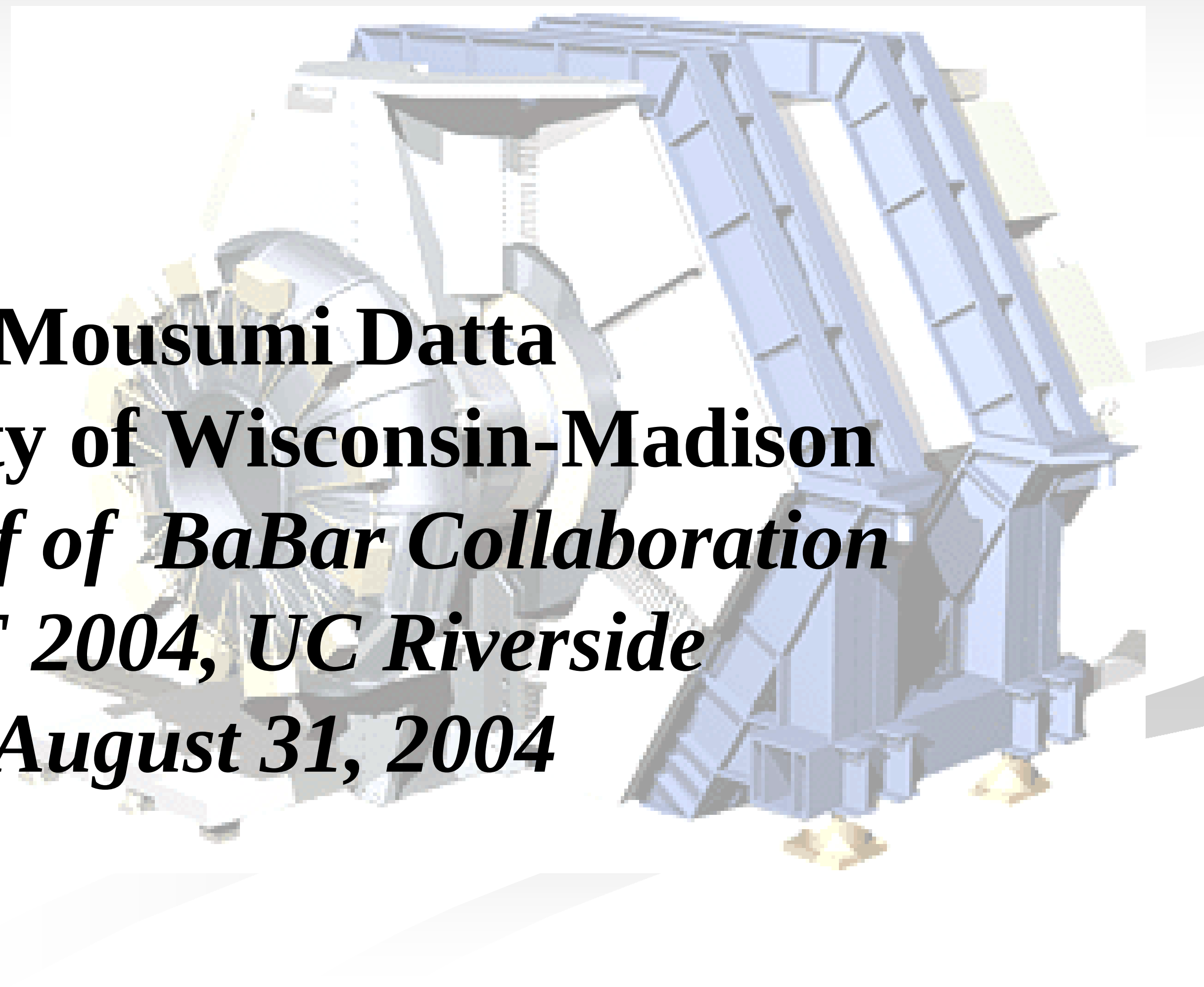
Search for the Rare Leptonic Decay $B \to \tau\nu$ at BaBar



Mousumi Datta
University of Wisconsin-Madison
On Behalf of BaBar Collaboration

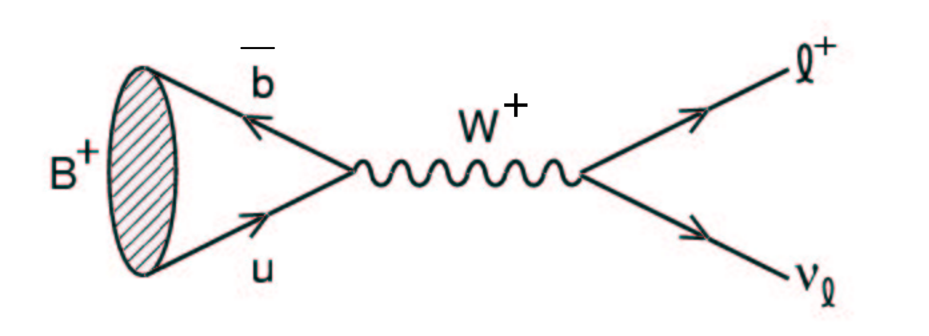
DPF 2004, UC Riverside
August 31, 2004

Outline

- Physics motivation
- Analysis strategy
- $B \to \tau\nu$ searches at BaBar on 81.9 fb^{-1} on-resonance data (submitted to PRL)
  - Search for $B \to \tau\nu$ recoiling against hadronic B
  - Search for $B \to \tau\nu$ recoiling against $D^0 l\nu X$
- Search for $B \to \tau\nu$ recoiling against $D^{*0} l\nu$ (preliminary)

  Newest method
  - $D^{*0} l\nu$ reconstruction
  - Signal selection
  - Physics results
  - Combined results: $D^{*0} l\nu$ and hadronic B samples
- Summary and outlook

Physics Motivation



- Purely leptonic B decay. Standard Model branching ratio

$$BR(B \rightarrow \ell\, \nu) = \frac{G_F^2 |V_{ub}|^2}{8\pi} f_B^2 \cdot \tau_B \cdot m_B \cdot m_\ell^2 \cdot \left[1 - \frac{m_\ell^2}{m_B^2}\right]^2$$

- Provide direct measurement of B meson decay constant ***f_B***

  $f_B = 0.196 \pm 0.032$ GeV (PDG 2004, Lattice QCD)

- Extract **$|V_{ub}| / |V_{td}|$** by combining branching ratio measurement with results from B mixing

- Sensitive to charged Higgs

Branching Ratio Expectations

- Helicity Suppressed: $BR(B \to \ell\,\nu) \propto m_\ell^2$

$\tau : \mu : e = 1 : 5 \times 10^{-3} : 1 \times 10^{-7}$

- Standard model estimate using 2004 PDG values:

$f_B = 0.196 \pm 0.032$ GeV
$|V_{ub}| = (3.67 \pm 0.47) \times 10^{-4}$

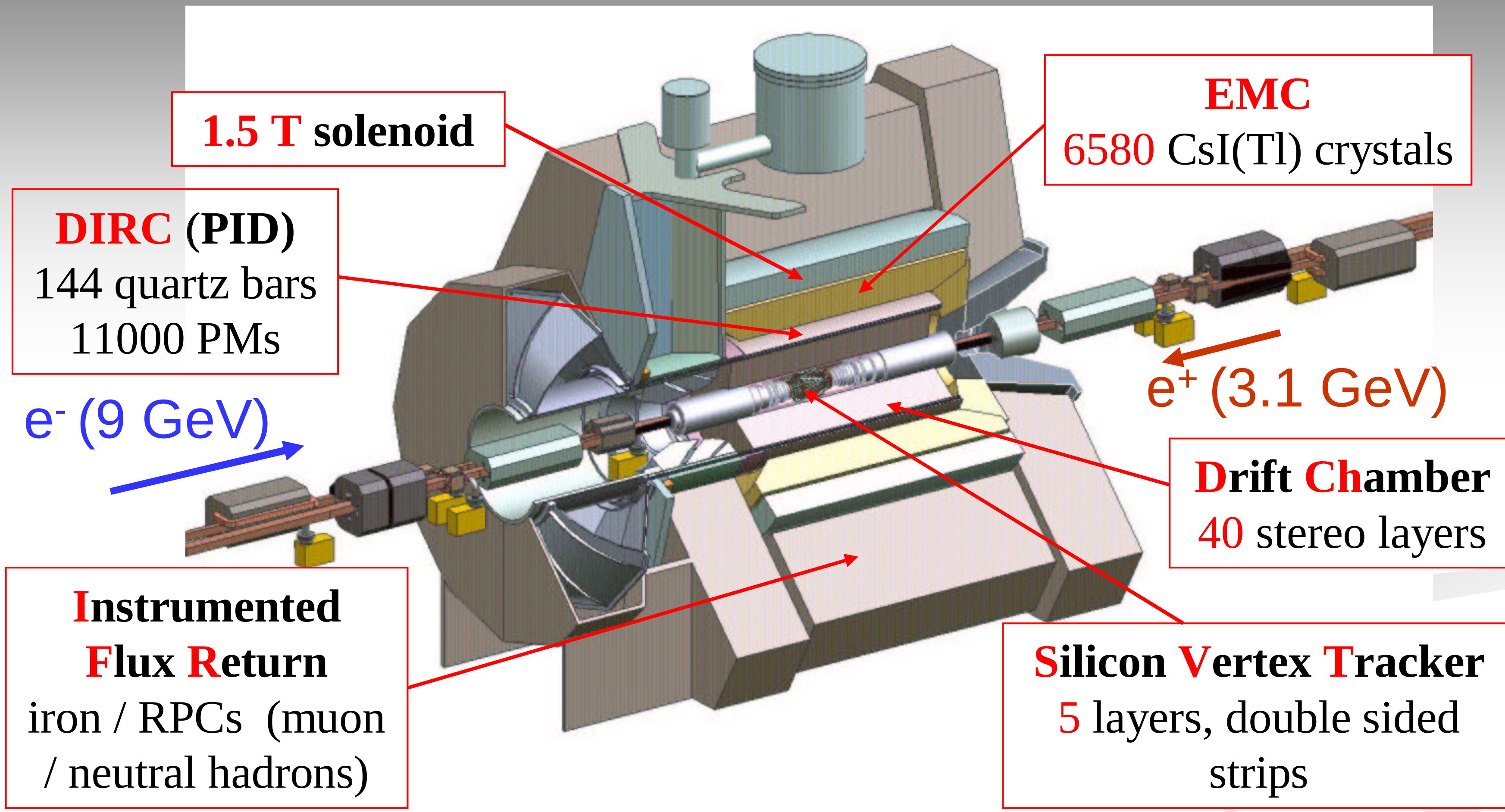
$BR(B \to \tau\nu) = (9.3 \pm 3.9) \times 10^{-5}$

- Existing upper limits from other experiments at 90% CL

LEP (L3): $BR(B \to \tau\nu) < 5.7 \times 10^{-4}$ (Phys. Lett. B 396, 327 (1997))

Belle: $BR(B \to \tau\nu) < 2.9 \times 10^{-4}$ (Preliminary (2004), on 140 fb^{-1} on-resonance data)

The BaBar Detector



SVT: 97% efficiency, 15 mm z hit resolution (inner layers, perp. tracks)

SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$

DIRC: K-π separation 4.2 σ @ 3.0 GeV/c $\rightarrow$ 2.5 σ at 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$ $\rightarrow$ 3% for E≈1 GeV, 6% for E≈20 MeV

Analysis Strategy

- In B-factory environment

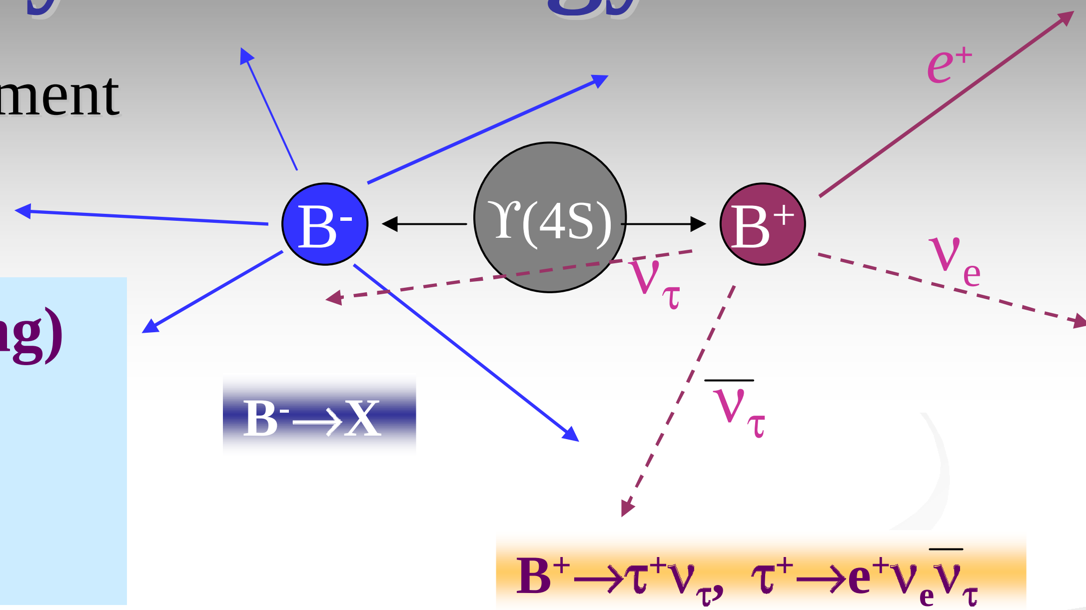
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^+B^-$

$B\rightarrow\tau\nu$, $B\rightarrow X$ (X=anything)

Main τ decay modes

$\tau\rightarrow(e, \mu)\nu\bar{\nu}$

$\tau\rightarrow(\pi, \pi\pi^0, \pi\pi\pi)\nu$



- First reconstruct one of the B-mesons, referred as "tag *B*" or "tag side".
- Make requirements on the remaining tracks/neutrals that constrain them to be consistent with τ decay. This remaining part of the event is referred as "signal side".

Submitted to PRL (hep-ex/0407038)

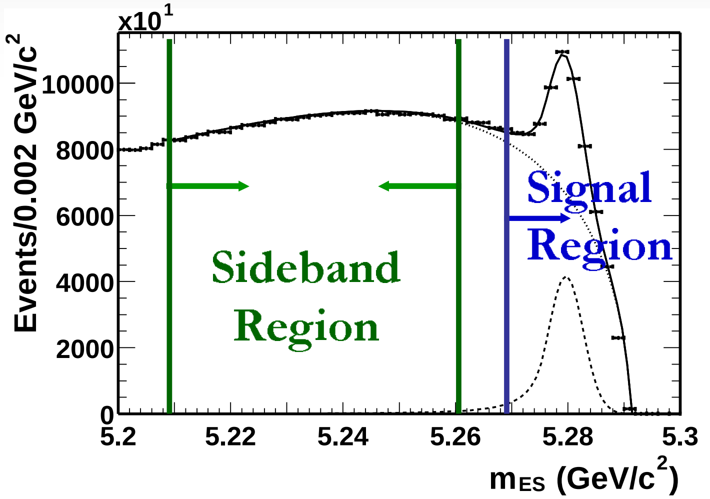
$81.9\ fb^{-1}$

Search for $B \rightarrow \tau\nu$ using Hadronic B Tags

Tag B reconstructed in a set of hadronic final states: $B^{\pm} \rightarrow D^{(*)0} X_{had}$

$X_{had} = n_1\pi^{\pm} + n_2K^{\pm} + n_3\pi^0 + n_4K^0_s$ (n_1=1,..5, n_2=0,..2, n_3=0,..2, n_4=0,1)

$D^{*0} \rightarrow D^0\pi^0$, $D^0 \rightarrow K\pi$, $K\pi\pi^0$, $K3\pi$, $K_s\pi\pi$



Fit for background and signal in beam energy substituted mass (m_{ES}) distribution to obtain reconstructed B yield:

$(167.8 \pm 1.2_{stat} \pm 3.0_{syst}) \times 10^3$

Signal τ identified in one of the modes

$\tau \rightarrow (e, \mu)\nu\bar{\nu}$

$\tau \rightarrow (\pi, \pi\pi^0, \pi\pi\pi)\nu$

- **Requirement on track and (or) π^0 multiplicity, particle identification, missing momentum, intermediate resonances ($\pi\pi^0\nu$, $\pi\pi\pi\nu$).**
- **Require at most one signal side γ candidate with 50 < E_γ < 100(110) MeV in lab frame (not associated with π^0).**

Submitted to PRL (hep-ex/0407038)

81.9 fb^{-1}

Physics Results : Hadronic B Tags

Mode	Signal-side Efficiency (%)	Expected Background	Obs. Events
$e\nu\bar{\nu}$	3.4 ± 0.1	$0.7\pm0.4\pm0.1$	2
$\mu\nu\bar{\nu}$	1.9 ± 0.1	$0.9\pm0.5\pm0.1$	0
$\pi\nu$	2.6 ± 0.1	$1.3\pm0.6\pm0.2$	2
$\pi\pi\pi\nu$	0.6 ± 0.1	$4.3\pm1.0\pm0.3$	4
$\pi\pi\nu$	2.0 ± 0.1	$10.0\pm1.6\pm1.3$	7
all	10.5 ± 0.2	$17.2\pm2.1\pm1.3$	15

Branching fraction upper limit

$BR(B\rightarrow\tau\nu) < 4.2 \times 10^{-4}$ at 90% CL

Use statistical techniques based on Higgs searches at LEP.

(A. L. Read, J. Phys. G28, 2693 (2002))

Submitted to PRL (hep-ex/0407038)

$81.9\ fb^{-1}$

Search for $B \rightarrow \tau\nu$ using $D^0 l\nu X$ Tags

- Tag B reconstructed as $D^0 l\nu X$

$X = \pi^0$, γ or nothing (X not reconstructed). **$D^0 \rightarrow K\pi$, $K\ \pi\pi^0$, $K3\pi$, $K_s\pi\pi$**

- Signal τ is identified only in the leptonic modes : **$\tau \rightarrow (e, \mu)\nu\bar{\nu}$**

- Total selection efficiency **$(4.19 \pm 0.31_{stat} \pm 0.36_{syst}) \times 10^{-4}$**

Branching fraction upper limit

$BR(B \rightarrow \tau\nu) < 6.7 \times 10^{-4}$ at 90% CL

$D^0 l\nu X$ tag sample is combined with statistically independent hadronic tag B sample. Combined upper limit

$BR(B \rightarrow \tau\nu) < 4.2 \times 10^{-4}$ at 90% CL

A new analysis is performed on $112.5\ fb^{-1}$ on-resonance data using $D^{*0} l\nu$ tags (a cleaner subset of the $D^0 l\nu X$ tags). In the signal side the τ is identified in both leptonic and hadronic modes.

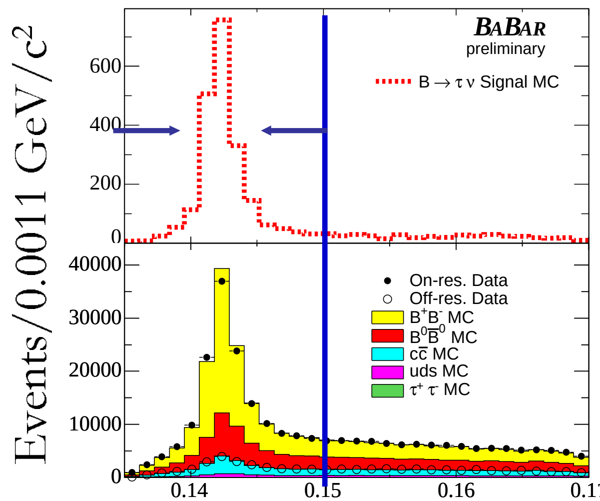
$D^{*0}l\nu$ Tag Reconstruction

112.5 fb^{-1}

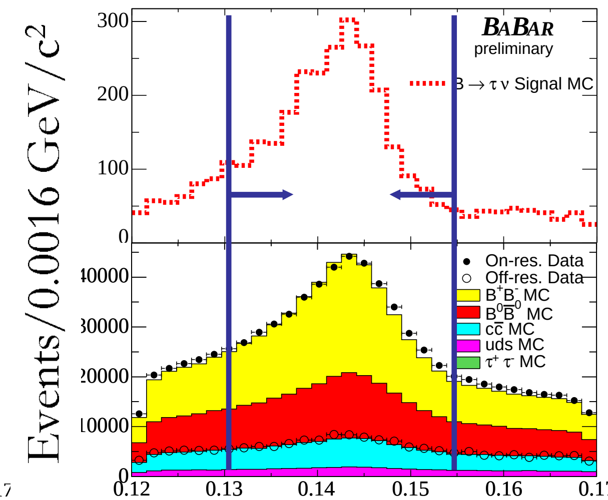
Use 112.5 fb^{-1} at Υ(4S) resonance data $\Rightarrow$ 124.1$\times 10^6$ B pairs

$B^- \rightarrow D^{*0}\, l^-\, \nu$

- $\rightarrow D^0\, \pi^0/\gamma$
  - $\rightarrow K^-\, \pi^+$
  - $\rightarrow K^-\, \pi^+\, \pi^0$
  - $\rightarrow K^-\, \pi^+\, \pi^-\, \pi^+$
  - $\rightarrow K^0_s\, \pi^+\, \pi^-$



ΔM (GeV/c²): (D⁰π⁰)eν



ΔM (GeV/c²): (D⁰γ)eν

- $\Sigma Q_{event} = 0$
- Requirement on ΔM (D^{*0}-D^0 mass difference)
- Lepton $P^* > 1$ GeV

- $-1.1 < \cos\theta_{B,D^{*0}l} < 1.1$

$$\cos\theta_{B,D^{*0}l} = \frac{\left(2E_B E_{D^{*0}l} - m_B^2 - m_{D^{*0}l}^2\right)}{2\left|\vec{p}_B\right|\left|\vec{p}_{D^{*0}l}\right|}$$

$$\varepsilon_{tag} = (1.82 \pm 0.074 \pm 0.055)\times 10^{-3}$$

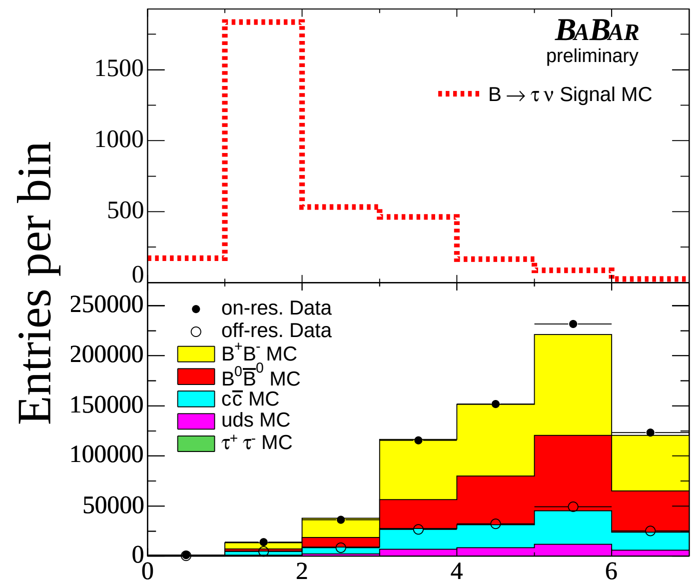
$B\to\tau\nu$ Signal Selection: $D^{*0}l\nu$ Tags

In the signal side the τ is identified in one of the following modes $\tau\to(e,\mu)\nu\bar{\nu}$, $\tau\to(\pi, \pi\pi^0, \pi\pi\pi)\nu$

- Signal-side track and (or) π^0 multiplicity
- Signal track(s) identified as e, μ or π, as appropriate.
- Missing mass requirements
- Electron $P^* < 1.4$ GeV for $\tau\to e\nu\nu$ mode
- Requirements on intermediate resonances

$$\tau\to\rho\nu,\ \ \rho\to\pi\pi^0$$

$$\tau\to a_1\nu,\ \ a_1\to\rho\pi,\ \ \rho\to\pi\pi$$



Signal-side track multiplicity

E_{extra} : $D^{*0}l\nu$ Tags

112.5 fb^{-1}

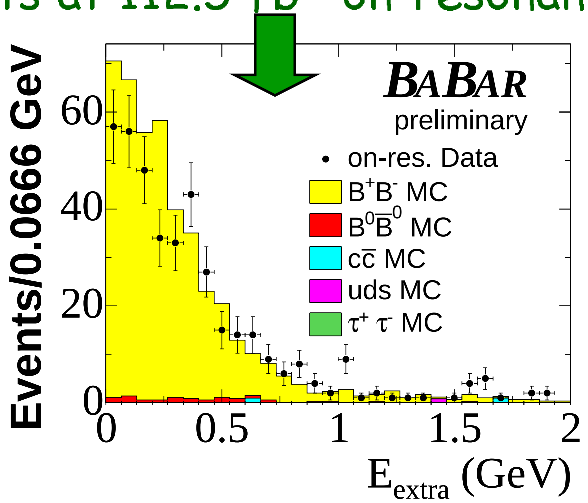
E_{extra} is the total energy in CM frame of all the neutrals, which are not associated with the tag side, or the signal τ in case of $\tau \to \pi\pi^0\nu$ decay.

- E_{extra} is the most powerful variable to separate signal from background
  - Signal events peaks at low E_{extra} value
    - Extra neutrals only from beam-background, hadronic split-offs, bremsstrahlung etc.
  - Background events peaks towards higher E_{extra} value
- Signal region: E_{extra}< 0.3 GeV

- Use "double-tagged" events for validation of E_{extra} simulation in the signal MC:

$$B^- \to D^{*0}\ell^-\overline{\nu}_\ell, \qquad B^+ \to \overline{D^{*0}}\ell^+\nu_\ell$$

407 reconstructed double-tagged events at 112.5 fb^{-1} on-resonance data



Systematic Uncertainties

112.5 fb^{-1}

- Estimation of number of $B\bar{B}$ pair (1.1%)
- Determination of tagging efficiency (3.1%)
  - Obtained using yield of double-tagged events in data and MC.
- Signal-side selection efficiency.
  - Tracking efficiency
  - Particle identification
  - Simulation of neutral clusters contributing to E_{extra} distribution
- Background estimation.

  Background estimation is performed by extrapolating the number of events in the E_{extra} side band in data in the signal region, using the shape of the variable from MC.
  - Systematic correction due to modeling of E_{extra} variable in background MC.

Selection Mode	Systematic error on signal-side efficiency (%)
$e\nu\bar{\nu}$	3.4
$\mu\nu\bar{\nu}$	4.0
$\pi\nu$	6.1
$\pi\pi^0\nu$	8.3
$\pi\pi\pi\nu$	6.3

Selection Mode	Systematic correction on bkg. estimation
$e\nu\bar{\nu}$	1.02 ± 0.04
$\mu\nu\bar{\nu}$	1.13 ± 0.06
$\pi\nu$	1.12 ± 0.03
$\pi\pi^0\nu$	1.09 ± 0.04
$\pi\pi\pi\nu$	1.07 ± 0.03

Preliminary

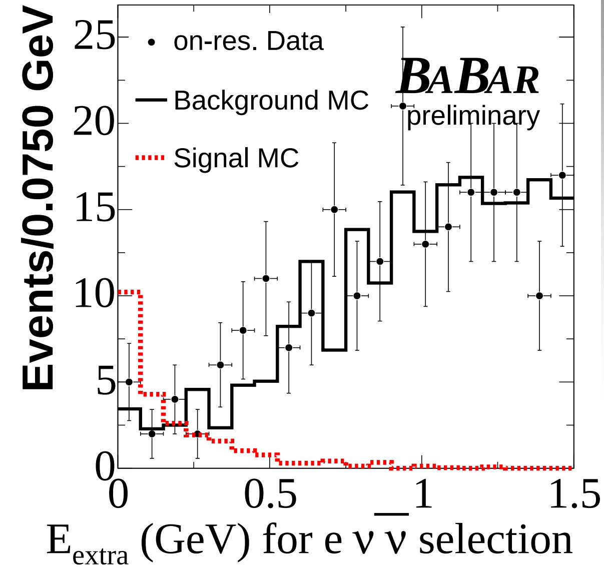
Physics Results : $D^{*0}l\nu$ Tags

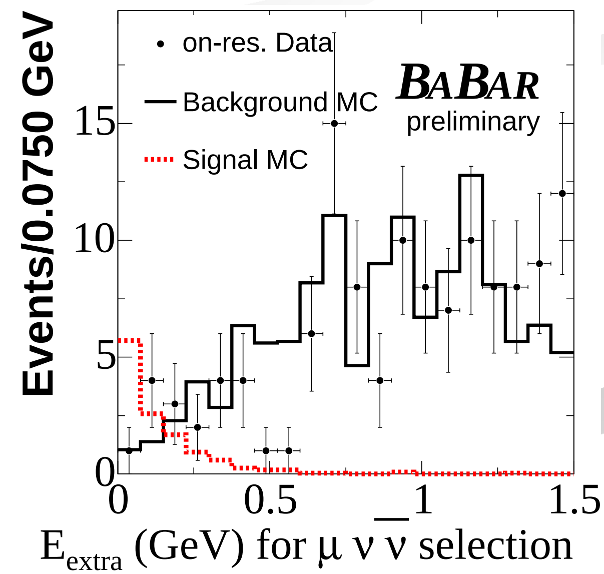
$112.5\ fb^{-1}$

Mode	Signal-side Efficiency (%)	Expected Background	Obs. Events
$e\nu\bar{\nu}$	8.36±0.42±0.28	15.15±3.14	13
$\mu\nu\bar{\nu}$	4.30±0.28±0.17	8.05±2.07	10
$\pi\nu$	22.34±0.72±1.36	55.30±7.37	72
$\pi\pi^0\nu$	3.01±0.24±0.25	29.80±5.10	30
$\pi\pi\pi\nu$	2.07±0.20±0.13	25.10±3.87	26
all	40.08±0.93±1.43	133.4±10.46	151

For BR($B\to\tau\nu$)=10^{-4}, signal to background ratios are ~1:6 for $e\nu\bar{\nu}$, ~1:8 for $\mu\nu\bar{\nu}$, ~1:9 for $\pi\nu$, ~1:34 for $\pi\pi^0\nu$, and ~1:51 for $\pi\pi\pi\nu$.

Background events contain K_L and/or neutrino, frequently tracks and (or) neutrals pass outside detector acceptance.





Preliminary

112.5 fb^{-1}

Branching Ratio Upper Limit : $D^{*0}l\nu$ Tags

- Use statistical techniques based on Higgs searches at LEP.

(A. L. Read, J. Phys. G28, 2693 (2002). Use same statistical method in hadronic tag analysis and $D^{*0}l\nu$ tag analysis)

- Define an estimator "Q" : monotonically increasing for increasing signal

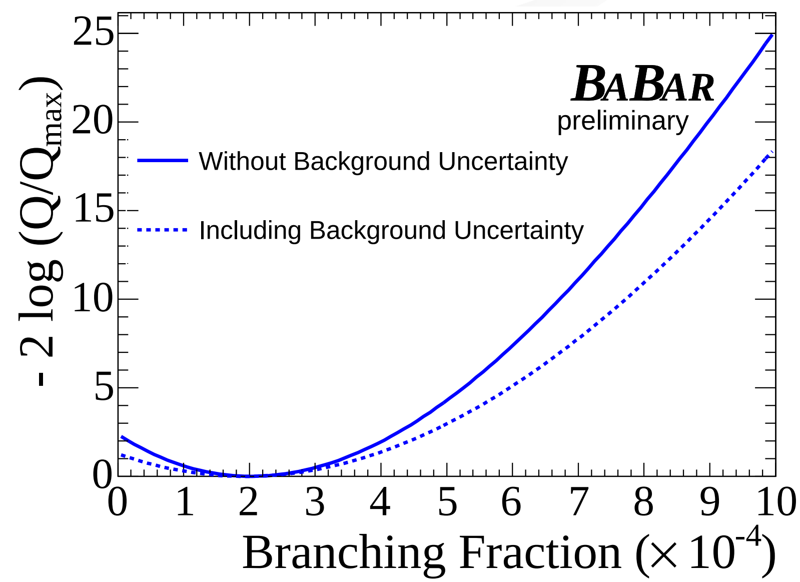
$$CL_s = CL_{s+b} / CL_b \qquad CL_{s+b} = P_{s+b}(Q \le Q_{obs}) \qquad CL_b = P_b(Q \le Q_{obs})$$

Branching fraction upper limit at 90% C.L.

$$BR(B \to \tau\nu) < 4.3 \times 10^{-4}$$

Central Value

$$BR(B \to \tau\nu) = 1.9^{+1.8}_{-1.7} \times 10^{-4}$$



Combined Results

- The hadronic tag sample is statistically independent of the semileptonic $D^{*0}l\nu$ tag sample.
- A combined likelihood ratio estimator is created by taking the product of the semiptonic (Q_{sl}) and hadronic (Q_{had}) likelihood ratio estimator: $Q_{comb} = Q_{sl} \times Q_{had}$

Hadronic Tag and $D^{*0}l\nu$ Tag Samples

Presented at ICHEP 2004 (hep-ex/0408091)

$BR(B \to \tau\nu) < 3.3 \times 10^{-4}$ at 90% CL

Central Value $BR(B \to \tau\nu) = 1.6^{+1.3}_{-1.2} \times 10^{-4}$

$f_B < 0.48$ GeV at 90% CL

Summary and Outlook

Tag side	$D^{*0}l\nu$	$D^{(*)0}X_{had}$	$D^0 l\nu X$
Signal side	$\tau\to(e,\mu)\nu\bar{\nu}$ $\tau\to(\pi,\pi\pi^0,\pi\pi\pi)\nu_\tau$	$\tau\to(e,\mu)\nu\bar{\nu}$ $\tau\to(\pi,\pi\pi^0,\pi\pi\pi)\nu$	$\tau\to(e,\mu)\nu\bar{\nu}$
Dataset	112.5 fb^{-1}	81.9 fb^{-1}	81.9 fb^{-1}
Results	$BR(B\to\tau\nu) < 4.3 \times 10^{-4}$ at 90% CL	$BR(B\to\tau\nu) < 4.2 \times 10^{-4}$ at 90% CL	$BR(B\to\tau\nu) < 6.7 \times 10^{-4}$ at 90% CL

- ✓ Combined upper limit from $D^{*0}l\nu$ and hadronic tag sample

  $BR(B\to\tau\nu) < 3.3 \times 10^{-4}$ at 90% CL (Preliminary)
- ✓ Combined upper limit from $D^0 l\nu X$ and hadronic tag sample

  $BR(B\to\tau\nu) < 4.2 \times 10^{-4}$ at 90% CL (Submitted to PRL)

The analyses using $D^{*0}l\nu$ and hadronic B tags will be updated on the ~220 fb^{-1} on-resonance dataset.

Backup Slides

Summary of Signal-Side Selection : $D^{*0}l\nu$ Tags

$e\nu\bar{\nu}$	$\mu\nu\bar{\nu}$	$\pi\nu$	$\pi\pi^0\nu$	$\pi\pi\pi\nu$
One signal track				3 signal tracks
Electron ID Muon veto Kaon veto	Muon ID Electron veto Kaon veto	Electron veto Muon veto Kaon veto		Pion ID Veto Electron, Muon, Pion
N/A	N/A	zero signal π^0	Non-zero signal π^0	N/A
Missing mass > 4 GeV		Missing mass > 3 GeV		Missing Mass > 2 GeV
P* of e < 1.4 GeV	N/A	P* of π < 2.7 GeV	P* of $\pi\pi^0$ < 2.7 GeV	P* of 3π < 2.7 GeV
N/A	N/A	N/A	$\rho^{\pm}$ selection	$a_1^{\pm}$ selection
$E_{extra} < 0.3$ GeV				

Signal-Side Selection Efficiency : $D^{*0}l\nu$ Tags

Decay mode in MC	Selection efficiency (%)				
	$e\nu\bar{\nu}$	$\mu\nu\bar{\nu}$	$\pi\nu$	$\pi\pi^0\nu$	$3\pi\nu$
$e\nu\bar{\nu}$	48.6	0.1	11.9	0.1	0
$\mu\nu\bar{\nu}$	0.1	25.8	53.3	0.7	0
$\pi\nu$	0	0.5	57.5	2.6	0
$\pi\pi^0\nu$	0	0.3	12.1	8.8	0
$\pi\pi\pi\nu$	0	0	1.1	0	27.6
$\pi\pi^0\pi^0\nu$	0	0	2.8	2.8	0
$\pi\pi\pi\pi^0\nu$	0	0	0.5	0	4.1
Other	1.2	2.1	10.0	2.5	1.0
Total (ε_i)	8.4	4.8	21.9	3.2	2.1
$\Sigma\varepsilon_i$	40.4				

Total signal-side efficiency for each selection

$$\varepsilon_i = \sum_{j=1}^{n_{decay}=8} \varepsilon_i^j f_j$$

ε_i^j is the efficiency of the selection i for the MC τ decay mode j,
$f_j = BR(\tau \rightarrow j)$

No systematic correction applied to efficiencies listed in the table

Tagging Efficiency Systematics

- Use double-tag yield in data and MC
- Number of double tag events (N_2) is related to the tag reconstructed efficiency (ε) and total number of B^+B^- events (N) as follows

$$N_2 = \varepsilon^2 N$$

- From double tag yield in data (407.0±20.2) and MC (434.4±12.4) obtain correction factor for tagging efficiency:

$$\varepsilon_{data}/\varepsilon_{MC} = 0.969 \pm 0.029$$

- The 3.1% error obtained form double-tag method is used as the systematic error.

$$\boldsymbol{\varepsilon_{tag} = (1.82 \pm 0.074 \pm 0.055)\times 10^{-3}}$$

Limit Setting Procedure used in $D^{*0}l\nu$ and Hadronic Tag Analyses

- Using a likelihood ratio estimator to combine different channels :

$$Q = \frac{L(s+b)}{L(b)}$$

$$L(s+b) = \prod_{i=1}^{n_{channels}} \frac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i}}{n_i!}, \quad L(b) = \prod_{i=1}^{n_{channels}} \frac{e^{-b}b_i^{n_i}}{n_i!}$$

$$s_i = N_{B\bar{B}} \cdot BR(B \rightarrow \tau\nu)\varepsilon_{tag} .\varepsilon_i$$

• Statistical and systematic uncertainties on expected backgrounds are included in the likelihood definition by convoluting with a Gaussian ***$G(b_i,\sigma_{bi})$,*** where b_i is the expected background and σ_{bi} is the uncertainty on background expectation.

$$L(s_i+b_i) \rightarrow L(s_i+b_i) \otimes G(b_i, \sigma_{b_i})$$

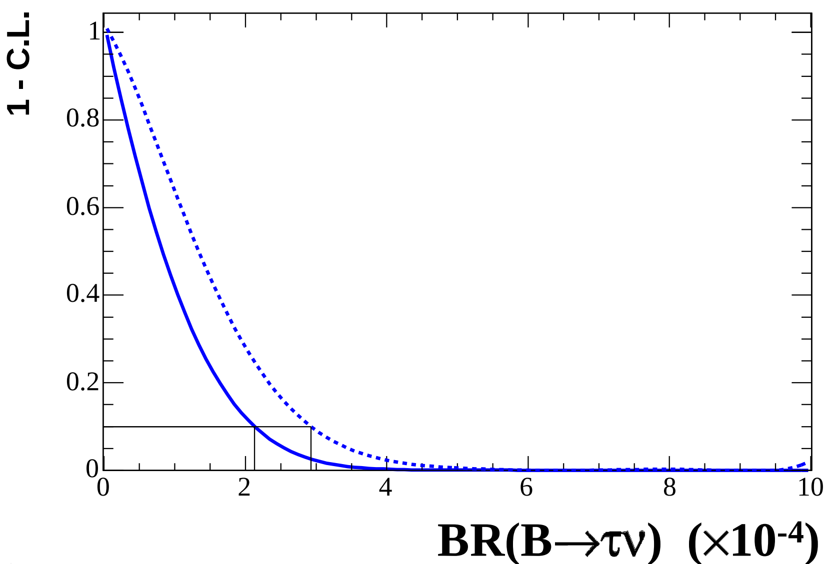
• Branching fraction upper limit calculated by running toy MC for different branching fraction hypothesis.

• The confidence level (C.L.) for certain signal hypothesis is computed as:

$$C.L._s = \frac{C.L._{s+b}}{C.L._b} = \frac{N_{Q_{s+b}<Q_{obs}}}{N_{Q_b<Q_{obs}}}$$

Nominal Upper Limit at 90% C.L.

- **Upper limit is calculated for the case when observed number of events in data is equal to the expected number of background events**
- **Including modes with worse signal to background ratio actually slightly improves sensitivity.**



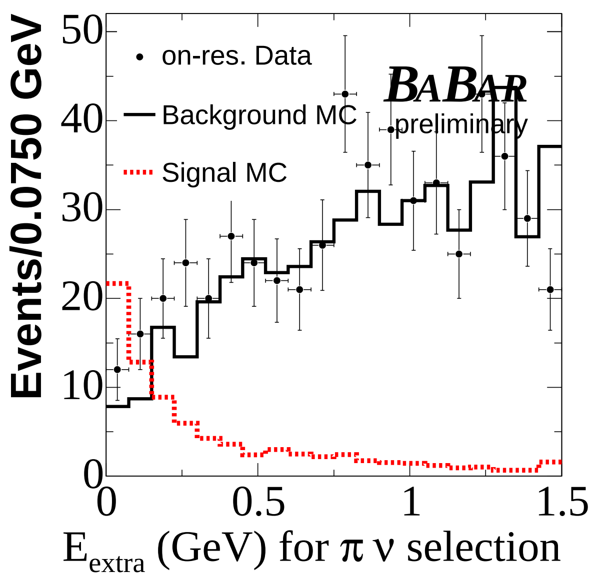
Modes	UL at 90% C.L. without Background Uncertainties $\times 10^{-4}$	UL at 90% C.L. including Background Uncertainties $\times 10^{-4}$
All	2.13	2.93
Ex. $3\pi\nu$	2.15	2.95
Ex. $\pi\pi^0\nu$, $3\pi\nu$	2.17	2.98
Ex. $\pi\nu$, $\pi\pi^0\nu$, $3\pi\nu$	3.37	4.27
$e\nu\bar{\nu}$	4.37	5.25
$\mu\nu\bar{\nu}$	7.11	8.11
$\pi\nu$	3.04	4.29

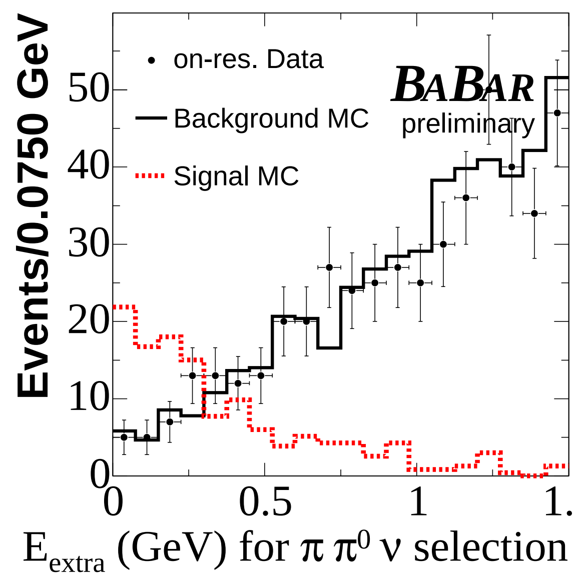
Preliminary

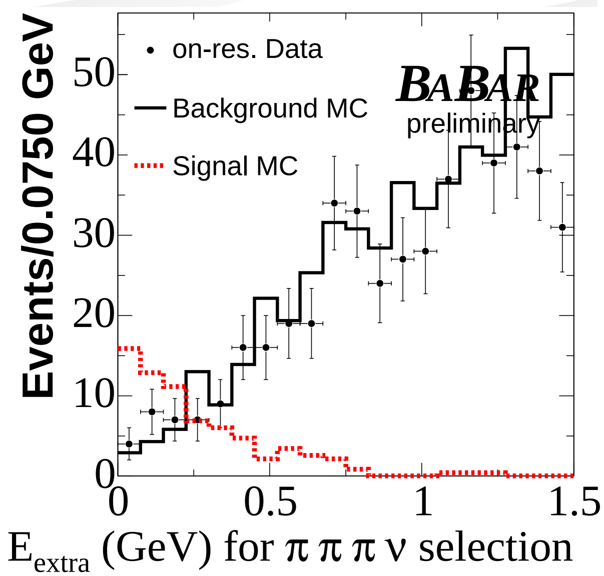
Physics Results : $D^{*0}l\nu$ Tags

112.5 fb^{-1}

	Signal-side Efficiency (%)	Expected Bkg.	Obs. Evt.	BR UL ($\times 10^{-4}$)
$e\nu\bar{\nu}$	8.36±0.42±0.28	15.15±3.14	13	4.5
$\mu\nu\bar{\nu}$	4.30±0.28±0.17	8.05±2.07	10	10.2
$\pi\nu$	22.34±0.72±1.36	55.30±7.37	72	7.5
$\pi\pi^0\nu$	3.01±0.24±0.25	29.80±5.10	30	24.1
$\pi\pi\pi\nu$	2.07±0.20±0.13	25.10±3.87	26	21.9
combined	40.08±0.93±1.43	133.4±10.46	151	4.3







Submitted to PRL (hep-ex/0407038)

$81.9\ fb^{-1}$

Search for $B \to \tau\nu$ using $D^0 l\nu X$ Tags

Tag B reconstructed as $D^0 l\nu X$

$X=\pi^0$, γ or nothing (X not reconstructed), **$D^0 \to K\pi$, $K\pi\pi^0$, $K3\pi$, $K_s\pi\pi$**

- D^0 mass < 3σ of fitted mean
- Lepton P* > 1 GeV
- $-2.5 < \cos\theta_{B,D0l} < 1.1$

$$\cos\theta_{B,D^0 l} = \frac{\left(2E_B E_{D^0 l} - m_B^2 - m_{D^0 l}^2\right)}{2\left|\vec{p}_B\right|\left|\vec{p}_{D^0 l}\right|}$$

Signal τ is identified only in the leptonic modes : $\tau \to (e, \mu)\nu_{(e,\mu)}\nu_\tau$

- One signal side track
- Signal track identified as e or μ
- Signal track $P^* < 1.2$ GeV
- $E_{extra} < 1$ GeV

Total selection efficiency

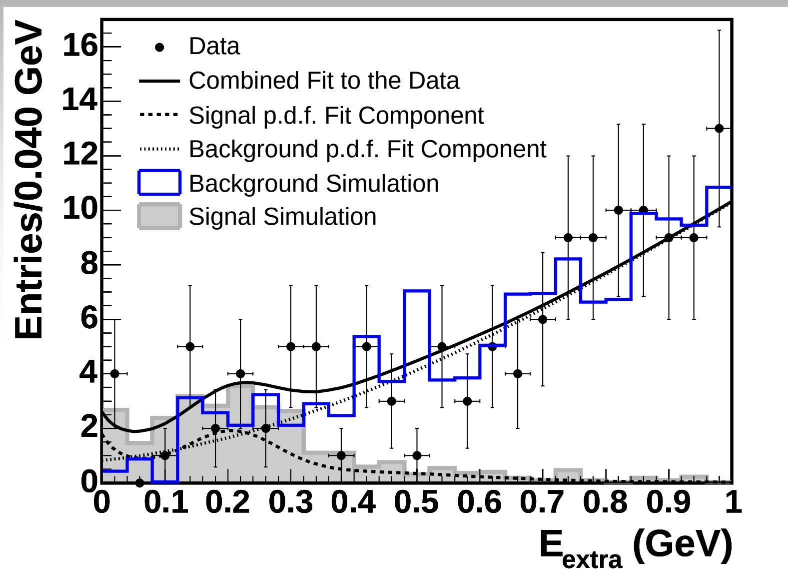
$(4.19 \pm 0.31_{stat} \pm 0.36_{syst}) \times 10^{-4}$

A maximum likelihood fit is performed on the E_{extra} distribution in data to extract signal and background contributions

Submitted to PRL (hep-ex/0407038)

81.9 fb^{-1}

Physics Results : $D^0 l\nu X$ Tags



	Fitted Yield
Signal	14.8±6.3
Background	115.2±11.8

2.3σ significance (statistical only) on signal yield.

- Upper limit on branching fraction obtained using "CLs method".
- Likelihood estimator Q is defined to be the fitted signal yield

$BR(B \to \tau\nu) < 6.7 \times 10^{-4}$ at 90% CL

Comparison of BaBar and Belle Results

- Belle has preliminary results on $B \rightarrow \tau\nu$ searches on a data set of 140 fb^{-1}

- For tag side hadronic B decay modes are used
- On the recoil both leptonic and hadronic τ decay modes are looked for

$$\tau \rightarrow (e, \mu)\nu\bar{\nu},\ \tau \rightarrow (\pi, \pi\pi^0, \pi\pi\pi)\nu$$

- Belle's analysis is similar to BaBar's hadronic tag analysis.
- Here we compare the efficiencies, background estimations and yields between the two analyses.

	BaBar	Belle
Dataset (fb^{-1})	81.9	140
Tag B Yield	1.68×10^5 (~2051/fb^{-1})	2.40×10^5 (~1714/fb^{-1})

Comparison of BaBar and Belle Results (cont')

BaBar (81.9 fb^{-1})

Mode	Signal-side efficiency (%)	Expected Bkg.	Obs. Events
$e\nu\bar{\nu}$	3.4 ± 0.1	$0.7\pm0.4\pm0.1$	2
$\mu\nu\bar{\nu}$	1.9 ± 0.1	$0.9\pm0.5\pm0.1$	0
$\pi\nu$	2.6 ± 0.1	$1.3\pm0.6\pm0.2$	2
$\pi\pi\pi\nu$	0.6 ± 0.1	$4.3\pm1.0\pm0.3$	4
$\pi\pi^0\nu$	2.0 ± 0.1	$10.0\pm1.6\pm1.3$	7
all	10.5 ± 0.2	$17.2\pm2.1\pm1.3$	15

Belle (140 fb^{-1})

Mode	Signal-side Efficiency (%)	Expected Bkg.	Obs. Events
$e\nu\bar{\nu}$	8.8 ± 0.3	9.4 ± 2.9	10
$\mu\nu\bar{\nu}$	9.2 ± 0.3	9.8 ± 2.9	6
$\pi\nu$	4.1 ± 0.2	5.4 ± 2.1	6
$\pi\pi\pi\nu$	1.6 ± 0.2	4.8 ± 1.6	3
$\pi\pi^0\nu$	1.8 ± 0.1	4.1 ± 1.6	3
all	25.5 ± 0.52	33.5 ± 5.0	28

Belle Results (ICHEP 2004)