Search for Rare Leptonic B Decays at

BABAR

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Outline

- Very brief overview of rare leptonic B decays
  - $B \to l\nu$, $B \to l^+l^-$, $B \to \nu\bar{\nu}$, $B \to X_{s,d}\nu\bar{\nu}$
- Purely leptonic decay $B \to \tau\nu$
  - Overview of $B \to \tau\nu$ 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 $D^0 l\nu X$
  - Focus on search for $B \to \tau\nu$ recoiling against $D^{*0} l\nu$ on 210.6 fb^{-1} on-resonance data

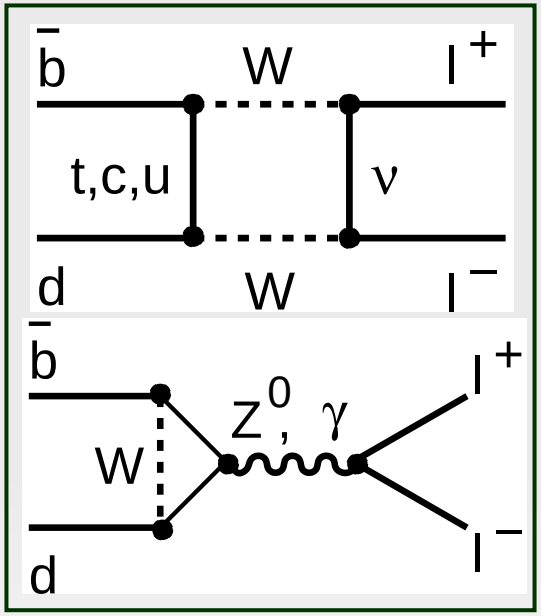
    New method
  - Future prospects and sensitivity
- Summary

Rare Leptonic B Decays in the SM

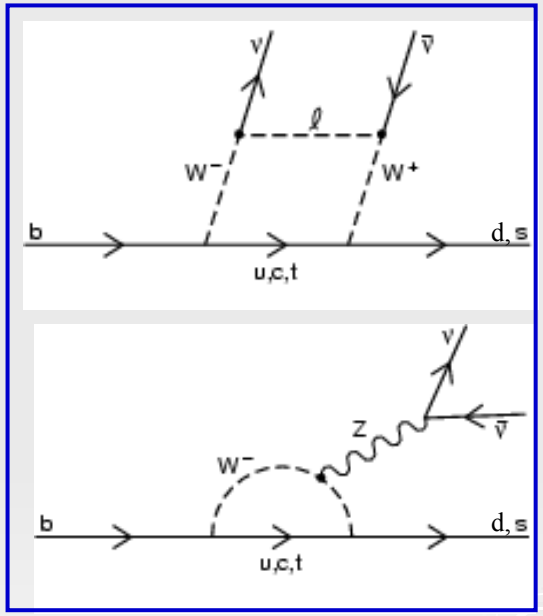
- Leptonic decays $B \to l\nu$, $B \to l^+l^-$, $B \to \nu\bar{\nu}$, $B \to X_{s,d}\nu\bar{\nu}$

$B \to l\nu$

W-boson annihilation



$B \to l^+l^-$



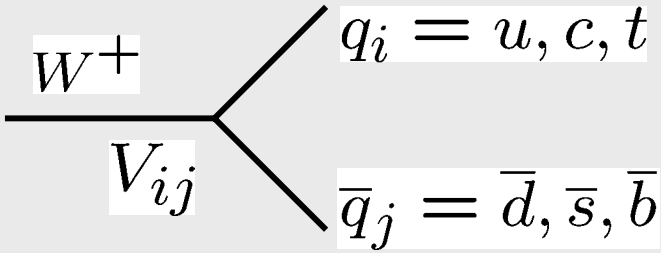
$B \to X_{d,s}\nu\bar{\nu}$

Electroweak penguin and W box diagram

Flavor Changing Neutral Current (FCNC)

Suppression in the SM

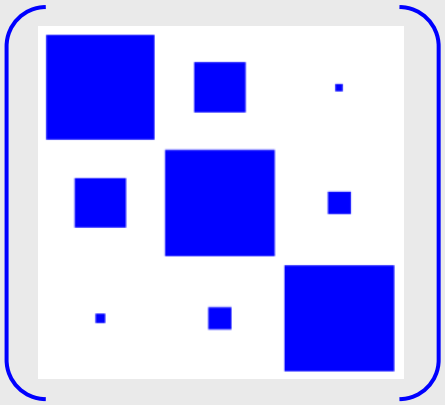
- CKM matrix elements



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

relative magnitudes

$$|V_{ij}| =$$



- CKM suppression: BR($B \to l\nu$) $\propto |V_{ub}|^2$

$|V_{ub}| \sim 4\times10^{-3}$

- FCNC processes: $B \to l^+l^-$, $X_{s,d}\nu\bar{\nu}$ involve V_{td} or V_{ts}

- Helicity suppression : Purely leptonic decays

$$BR(B \to l\nu) \propto m_l^2$$

SM Branching Ratio Expectation

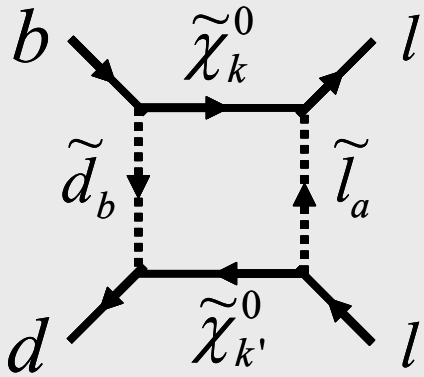
- Rare leptonic decay modes searched at BaBar

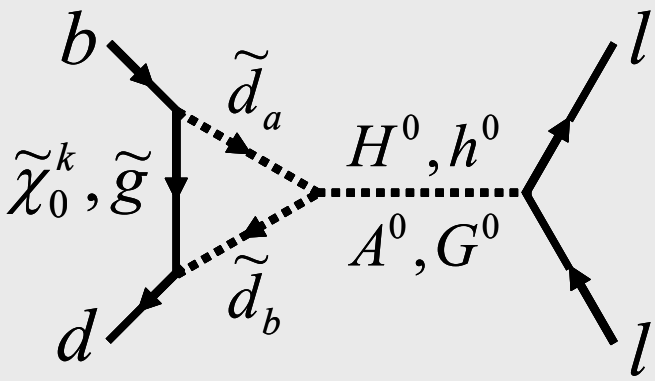
Decay Mode	SM Prediction
$B^0 \to e^+e^-$	2.4×10^{-15}
$B^0 \to \mu^+\mu^-$	1.0×10^{-10}
$B^0 \to e^\pm\mu^\mp$	-
$B^+ \to K^+\nu\bar{\nu}$	$3.8^{+1.2}_{-0.6}\times10^{-6}$
$B^+ \to \pi^+\nu\bar{\nu}$	$\propto \lvert V_{td}\rvert^2/\lvert V_{ts}\rvert^2$
$B \to \nu\bar{\nu}$	$\propto (m_\nu/m_{B^\circ})^2$
$B^+ \to \mu^+\nu$	4.2×10^{-7}

Note: $B^+ \to \tau^+\nu$ not included here, will be discussed in detail later

Physics Beyond the SM

- New physics contribution ⇒ significantly modify SM predicted rates
- Example: enhancement of BR($B \to \mu^+\mu^-$).
  (MSSM with Modified Minimal Flavor violation, Phys. Rev D 66, 074021 (2002))





$\tilde{l}_a \equiv$ *sleptons*

$\tilde{d}_a \equiv$ *down type squarks*

$\tilde{x}_k^0 \equiv$ *neutralinos*

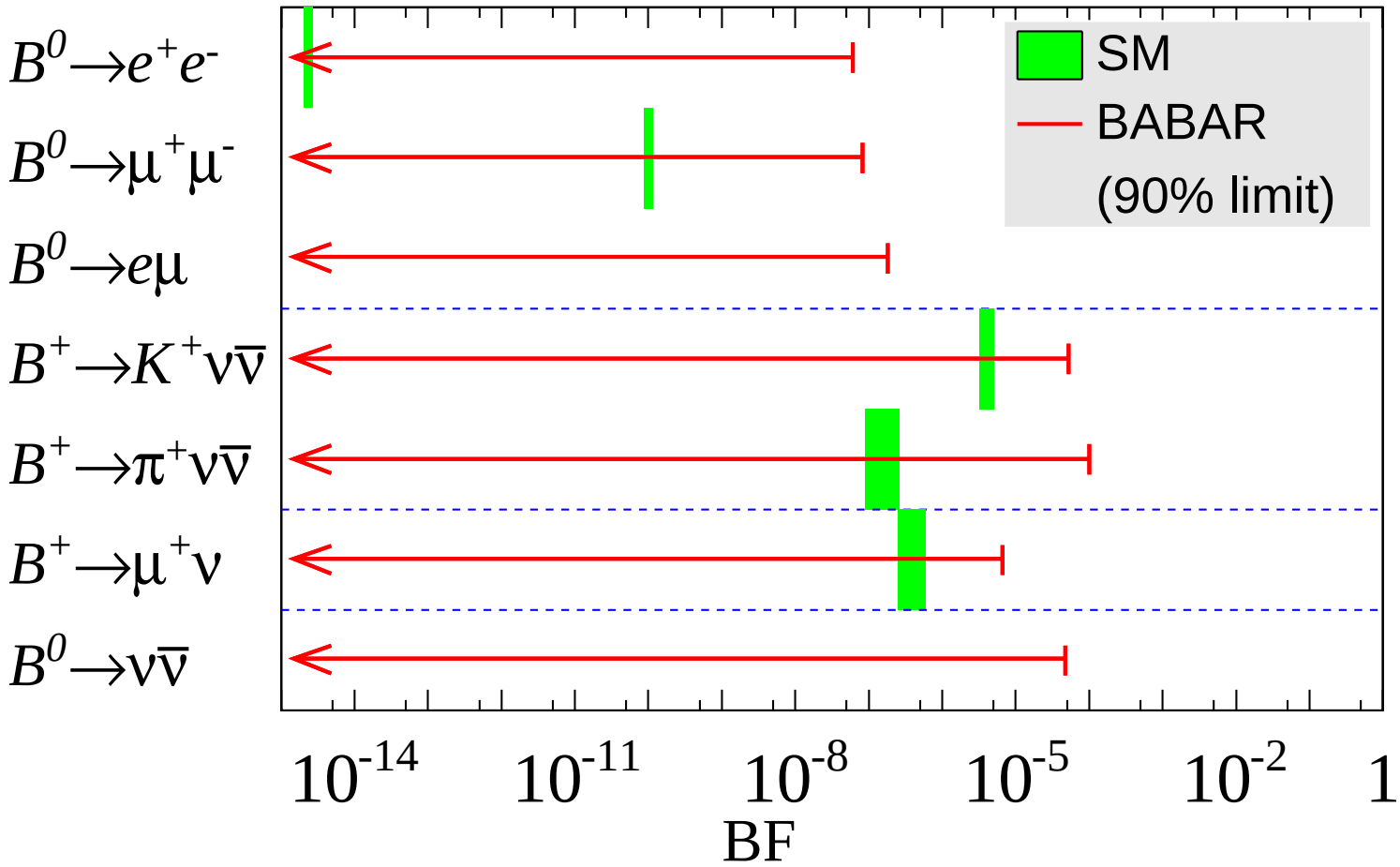
$\tilde{g} \equiv$ *gluino*

H^0, h^0, A^0, G^0 are Higgs and would-be-Goldstone Bosons

- BR($B \to \mu^+\mu^-$) can be enhanced up to 10^{-7}

CDF:	BR($B \to \mu^+\mu^-$) < 4.9×10^{-8} at 95% CL	(Preliminary, B. Abbott, SLAC Seminar)
BaBar:	BR($B \to \mu^+\mu^-$) < 8.3×10^{-8} at 90% CL	(Sub. to PRL, hep-ex/0408096)
CDF:	BR($B \to \mu^+\mu^-$) < 1.5×10^{-7} at 90% CL	(PRL 93, 032001 (2004))
Belle:	BR($B \to \mu^+\mu^-$) < 1.6×10^{-7} at 90% CL	(PRD 68, 111101 (2003))

Experimental Status: Rare Leptonic B Decays at BaBar



Note: $B^+ \to \tau^+\nu$ not included here, will be discussed in detail later

$B \to \tau\nu$

SM Theoretical Prediction

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+

- Standard Model (SM) branching ratio

$$BR_{SM}\left(B^- \to \ell^+ \nu\right) = \frac{G_F^2 m_B \tau_B}{8\pi} f_B^2 |V_{ub}|^2 m_\ell^2 \left[1 - \frac{m_\ell^2}{m_B^2}\right]^2$$

B meson decay constant.
⇒ *describes the overlap of the quark wave-functions inside the meson*

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Helicity suppressed
τ : μ : e =
$1 : 5\times10^{-3} : 1\times10^{-7}$

SM Branching Ratio Expectation

- The SM estimate using 2004 PDG values:

$$BR_{SM}(B\rightarrow\tau\nu) = (9.3\pm3.9)\times10^{-5}$$
$$BR_{SM}(B\rightarrow\mu\nu) = (4.2\pm1.7)\times10^{-7}$$
$$BR_{SM}(B\rightarrow e\nu) = (9.8\pm4.1)\times10^{-12}$$

$$f_B = (0.196\pm0.032)\ \text{GeV}$$
$$|V_{ub}| = (3.67\pm0.47)\times10^{-3}$$

Relatively large uncertainty (~40%) in the SM prediction
$\Rightarrow$ uncertainties in the values of f_B (~16%) and $|V_{ub}|$ (~13%)

- $BR_{SM}(B\rightarrow\tau\nu)$ is within the current experimental reach

f_B Measurement

- Provide direct measurement of B-meson decay constant f_B
  (Given measurement of $|V_{ub}|$ from semi-leptonic decays)
- Currently value of f_B is only know from theoretical calculations

$$f_B = 0.196 \pm 0.032 \text{ GeV}$$

(PDG 2004, Lattice QCD)

~16% error on f_B

- Uncertainty in f_B is a significant limitation on the extraction of $|V_{td}|$ from precision $B^0\bar{B}^0$ mixing measurements.

$$\Delta m_d = \frac{G_F^2}{6\pi^2} \eta_B \, m_B \, m_W^2 \, f_B^2 \, B_B \, S_0(x_t) \, |V_{td}|^2$$

World average of Δm_d
(0.502 ± 0.006) ps^{-1}
~1.2% error (HFAG, hep-ex/0412073)

$B_B = 1.26 \pm 0.10$
~8% error
(PDG 2004, Lattice QCD)

~19% uncertainty on $|V_{td}|$

Constraints on CKM Elements

- Extract $|\mathbf{V_{ub}}| / |\mathbf{V_{td}}|$ from $BR(B \to l\nu)/\Delta m_d$

$$\frac{BR_{SM}(B \to \ell\,\nu)}{\Delta m_d} = \frac{3\pi}{4}\frac{\tau_B m_\ell^2}{\eta_B\, m_W^2\, B_B\, S_0(x_t)}\left(1-\frac{m_\ell^2}{m_B^2}\right)^2 \frac{|V_{ub}|^2}{|V_{td}|^2}$$

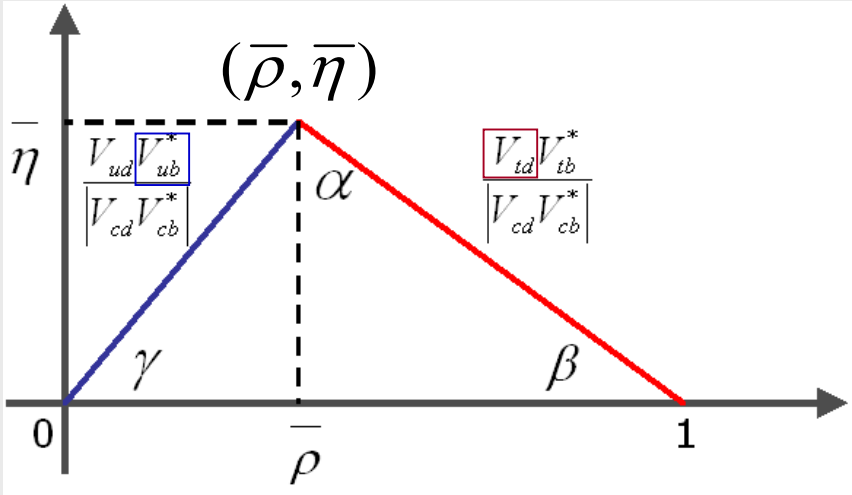
$$BR_{SM}(B \to \tau\nu) = \left((4.31 \pm 0.35)\times 10^{-4}\right)\frac{|V_{ub}|^2}{|V_{td}|^2}$$

- The ratio is independent of $f_B \Rightarrow$ ~4% theoretical uncertainty on $|V_{ub}|/|V_{td}|$

Constraints on CKM Elements (Cont')

- Unitarity condition of CKM matrix in the SM leads to triangle relations in the complex plane

$$V_{ud}V_{ub}^{*}+V_{cd}\ V_{cb}^{*}+V_{td}V_{tb}^{*}=0$$



$$\frac{|V_{ub}|^2}{|V_{td}|^2}=\frac{1}{\left[1-(\lambda^2/2)\right]^2}\cdot\frac{\bar{\rho}^2+\bar{\eta}^2}{(1-\bar{\rho})^2+\bar{\eta}^2}$$

$$\lambda=|V_{us}|=0.22$$

- $BR(B\rightarrow l\nu)/\Delta m_d \propto |V_{ub}|^2/|V_{td}|^2$ $\Rightarrow$ map out allowed zone in the plane of Wolfenstein ρ and η parameters.

Physics Beyond the SM for B→*l*ν

- Sensitive to contribution from physics beyond SM
  - In two Higgs doublet model (type II) (Phys. Rev. D. 48, 2342 (1993))

W^+, H^+

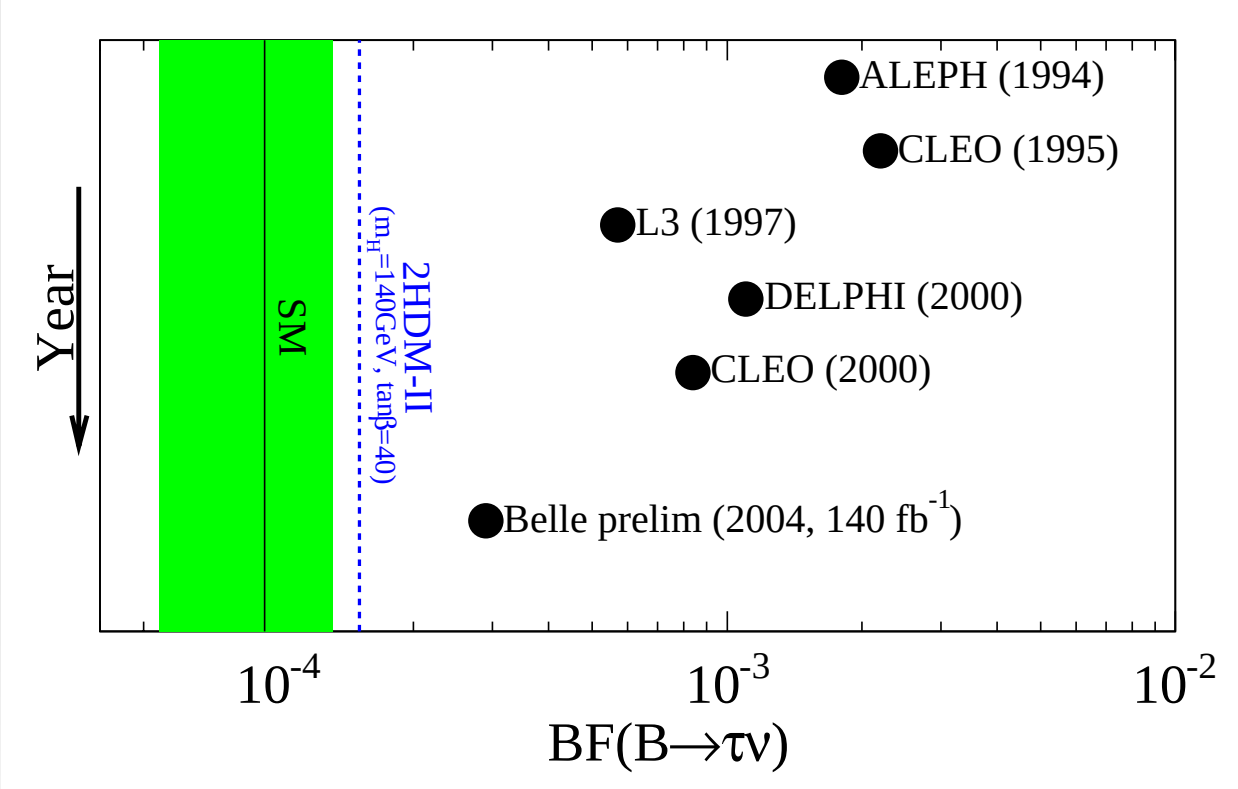
$$BR(B \to \ell\,\nu) = BR_{SM}(B \to \ell\,\nu) \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

tanβ is the ratio of vacuum expectation values for two Higgs doublets.

- Provide important constraints on $\tan\beta / m_{H^\pm}$
- Modification of the SM rate depends on the values of tanβ and $m_H \Rightarrow$ for m_H = 140 GeV, tanβ = 40, factor of ~1.6 enhancement

$B^+ \to \tau^+ \nu$ Searches at Other Experiments

- Existing upper limits at 90% CL from other experiments

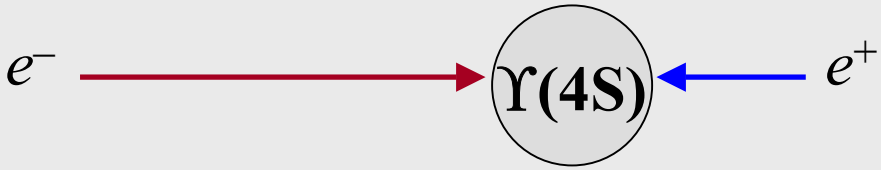


L3 (LEP):	$BR(B \to \tau\nu) < 5.7 \times 10^{-4}$	(Phys. Lett. B 396, 327 (1997))
Belle:	$BR(B \to \tau\nu) < 2.9 \times 10^{-4}$	Preliminary (2004), on 140 fb^{-1} on-resonance data (hep-ex/0408144)

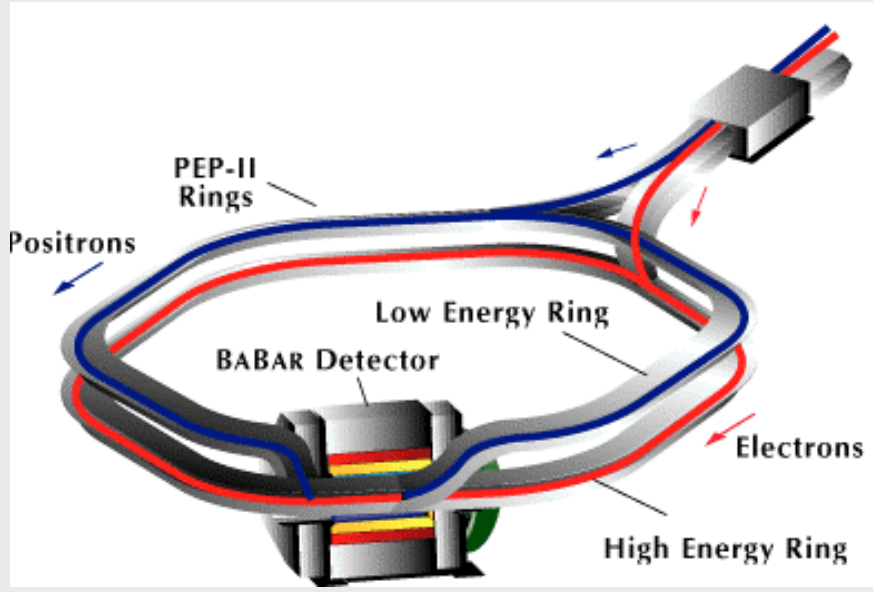
Search for $B^+ \rightarrow \tau^+ \nu$ at BaBar

PEP-II Asymmetric B-Factory at SLAC

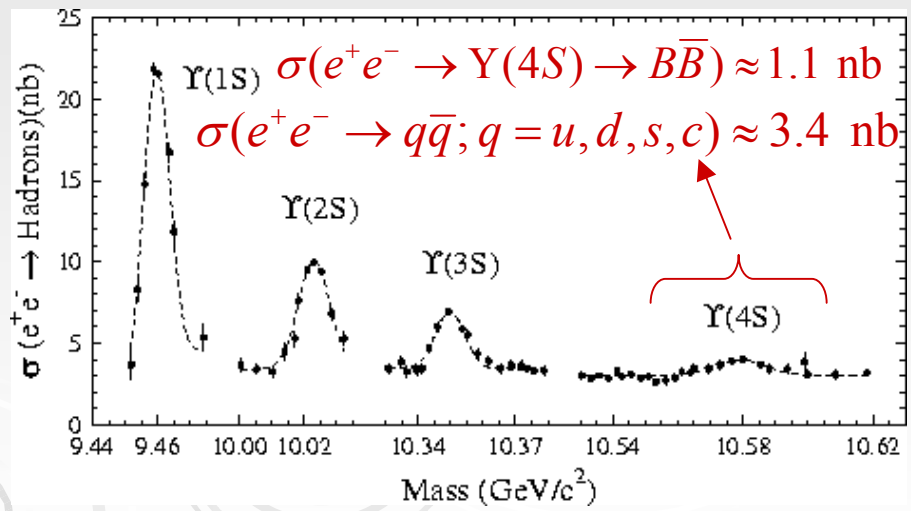
- Asymmetric beam energies



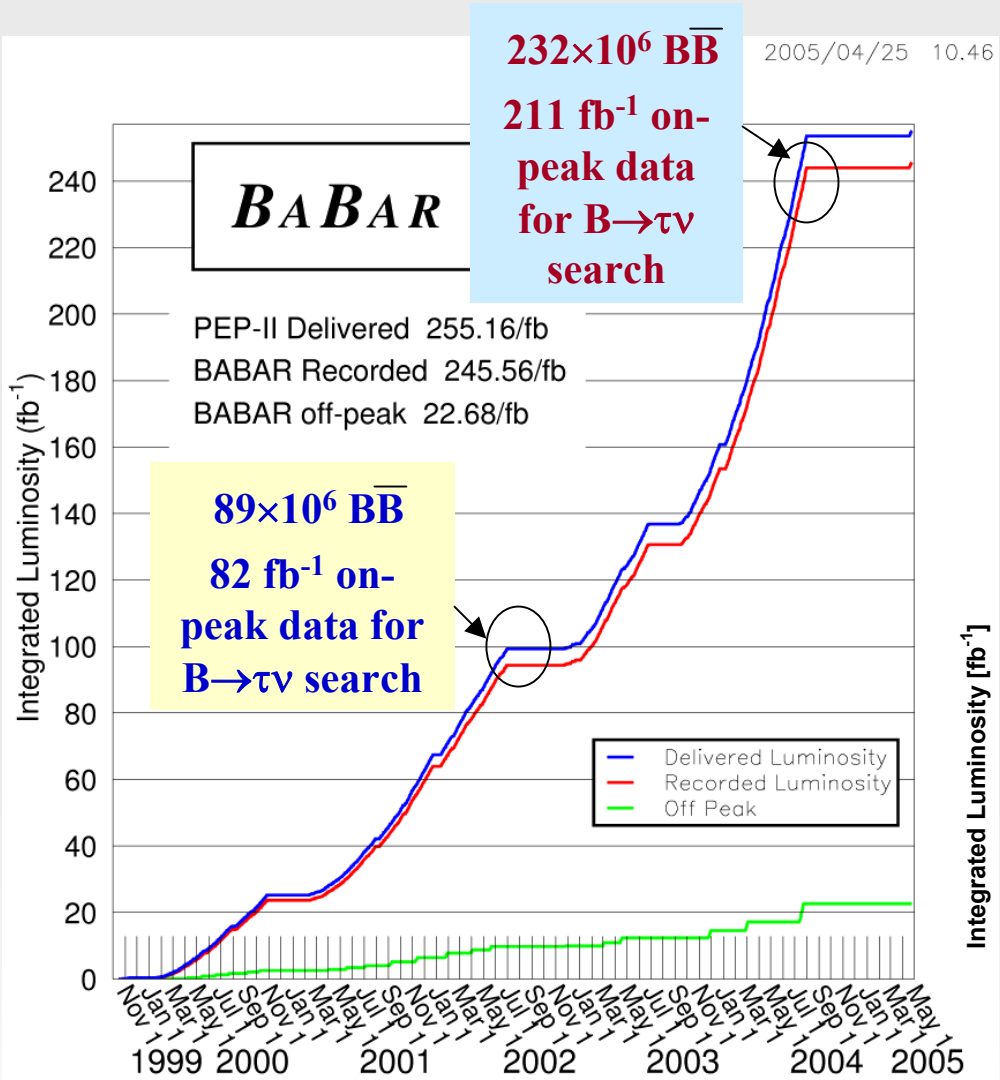
9 GeV e⁻ and **3.1 GeV e⁺**



- Operates at $\Upsilon(4S)$ resonance (10.58 GeV)
- $\Upsilon(4S) \rightarrow B^0\bar{B}^0$ or B^+B^- pairs
- B-mesons at lab have $\beta\gamma=0.56$
- B-mesons almost at rest in the $\Upsilon(4S)$ center-of-mass frame



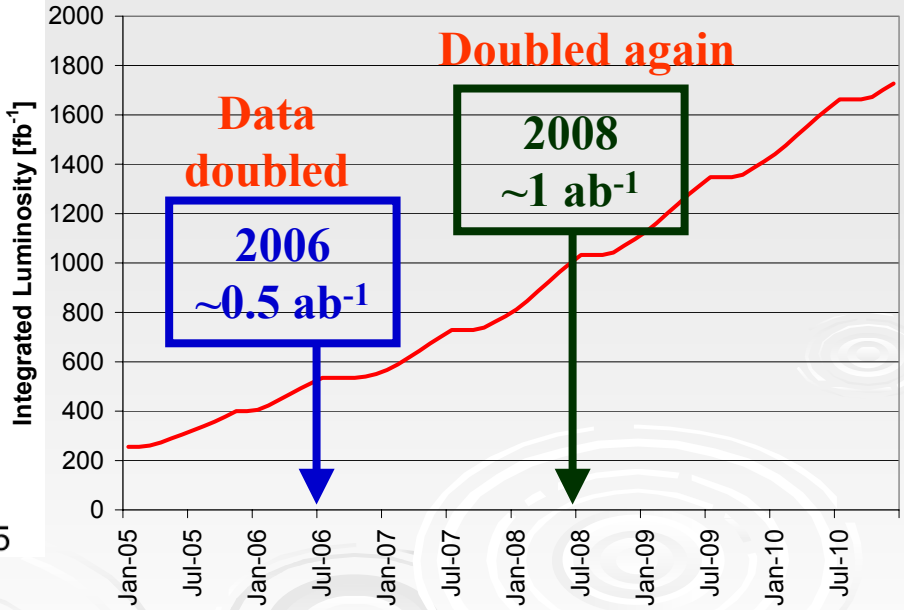
PEP-II Luminosity Performance



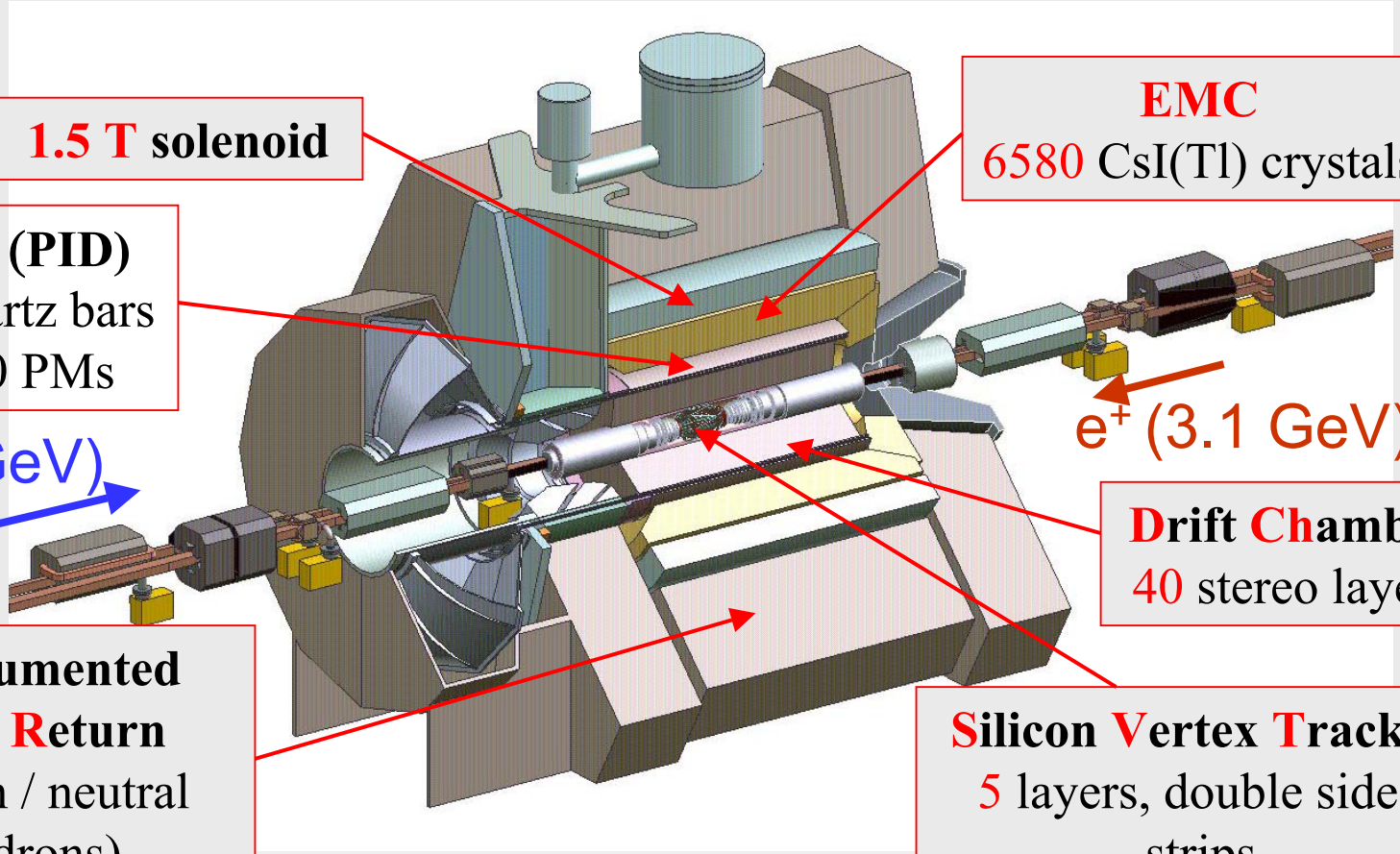
Best Performance

PEPII peak Luminosity:
9.213×10^{33} cm^{-2} sec^{-1}

Integrated Luminosity:
in 24 hours: 710.5 pb^{-1}



The BaBar Detector



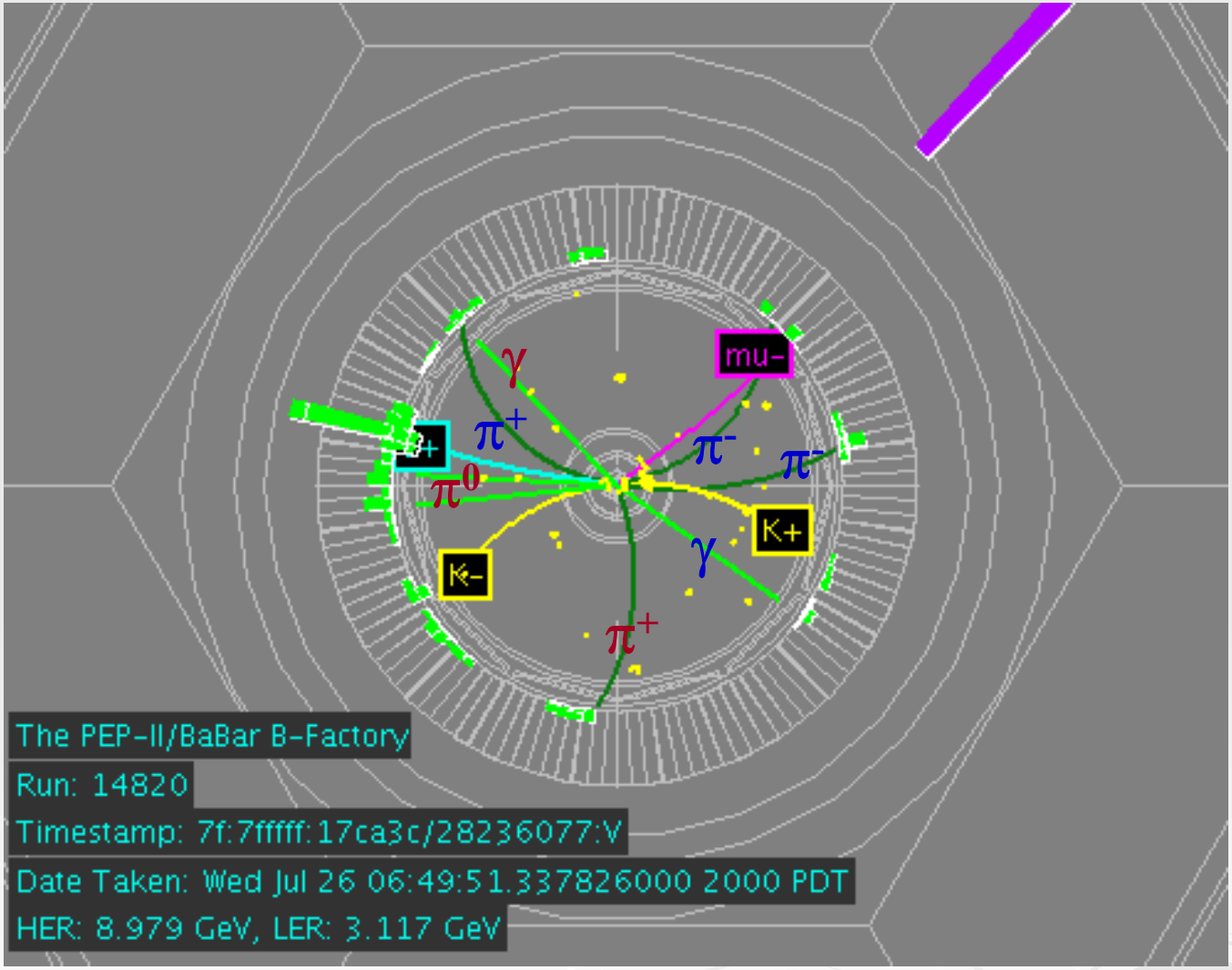
SVT: 97% efficiency, 15 mm z hit resolution (inner layers, perp. tracks)

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 → 2.5 σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \cdot E^{-1/4} \oplus 1.9\ \%$

A BaBar Event



Both of the B mesons in the event are reconstructed

$B^- \to D^{*0}\mu^-\bar{\nu}$
$\quad \hookrightarrow D^0\gamma$
$\quad\quad \hookrightarrow K^-\pi^+\pi^0$

$B^+ \to \bar{D}^{*0}e^+\nu$
$\quad \hookrightarrow \bar{D}^0\gamma$
$\quad\quad \hookrightarrow K^+\pi^-\pi^+\pi^-$

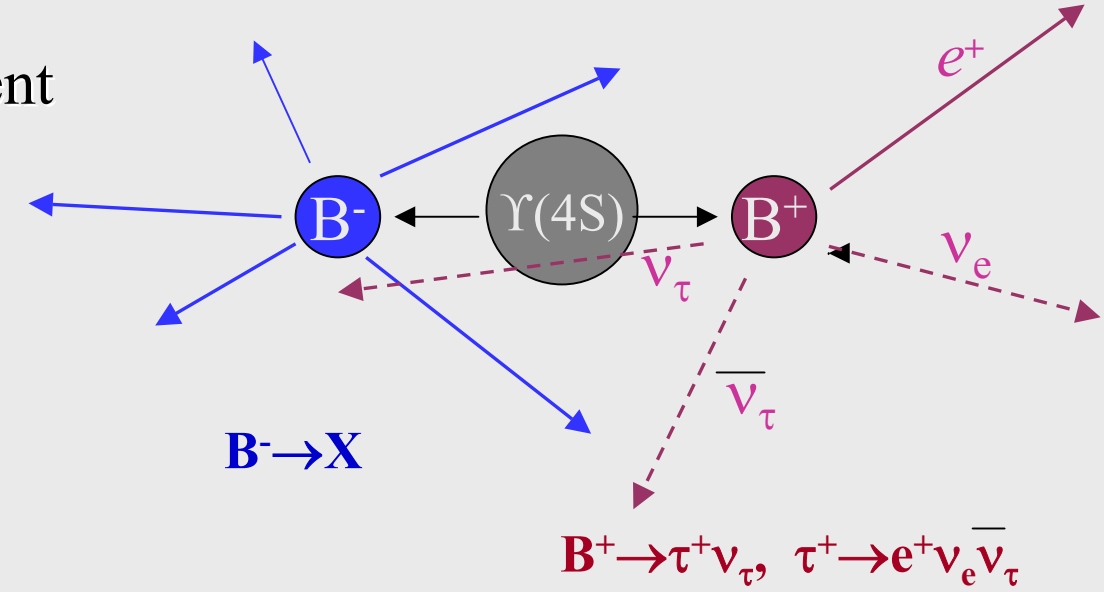
Relatively clean environment.

Analysis Strategy

- In B-factory environment

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

$B^+ \rightarrow \tau^+\nu$, $B^- \rightarrow X$



Main τ decay modes

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

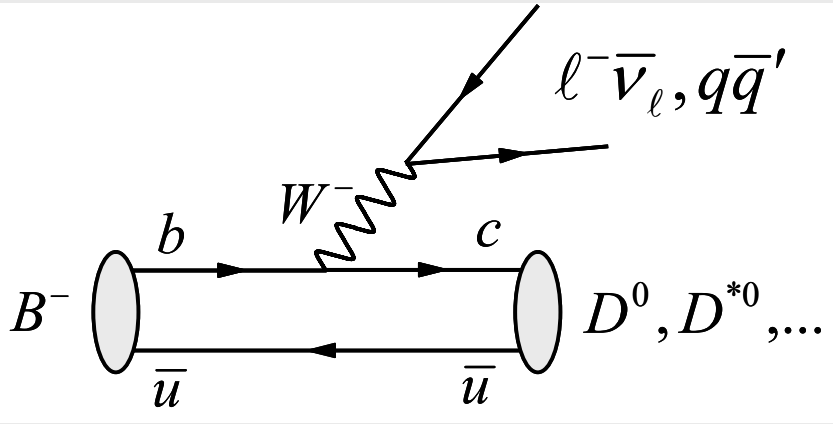
$\tau \rightarrow \pi\nu$, $\pi\pi^0\nu$, $\pi\pi\pi\nu$

- Multiple neutrinos in the final state $\Rightarrow$ very little experimental constraints
  - Reconstruct one of the B meson in the event
  - Compare the remaining particles in the event with the signature expected for the signal decay.

A relatively new technique $\Rightarrow$ exploits high luminosities at the B factories

Tag B

- Reconstruct one of the B-mesons, referred as the "**tag B**", in semi-leptonic or hadronic decay modes



Semi-leptonic Tag B

$B^- \rightarrow D^{(*)0}\, l^-\, \nu \quad (l = e, \mu)$

D^0
- $\rightarrow K^- \pi^+$
- $\rightarrow K^- \pi^+ \pi^0$
- $\rightarrow K^- \pi^+ \pi^- \pi^+$
- $\rightarrow K^0_s \pi^+ \pi^-$

Hadronic Tag B

$B^- \rightarrow D^{(*)0}\, X^-_{had}$

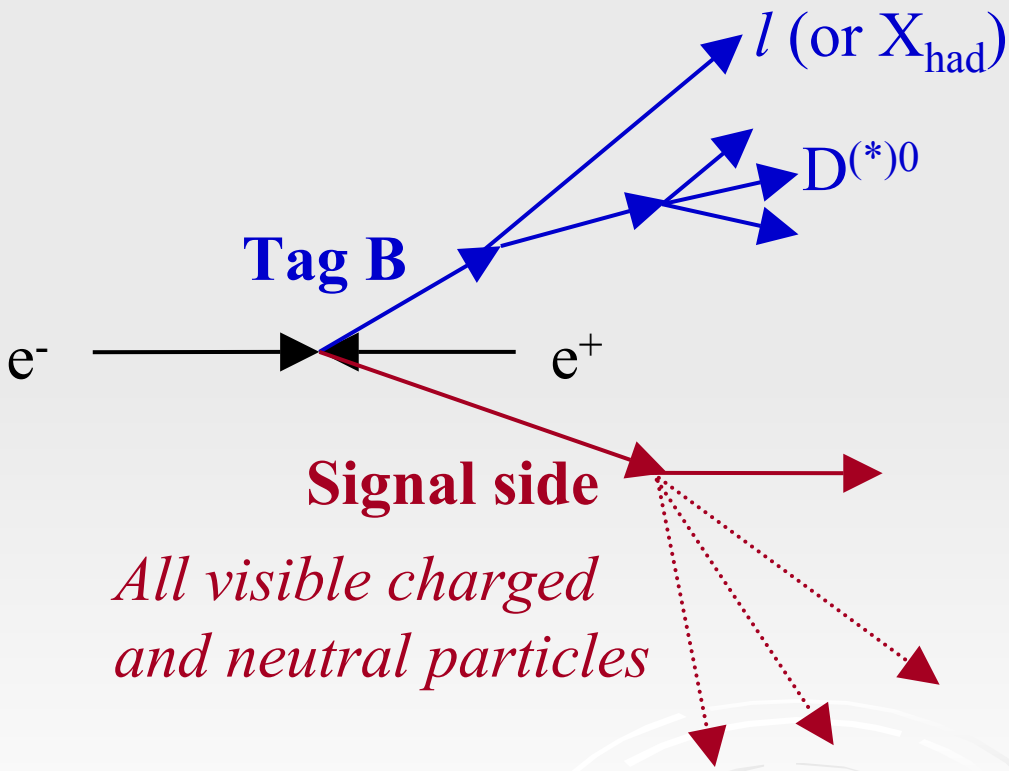
D^0
- $\rightarrow K^- \pi^+$
- $\rightarrow K^- \pi^+ \pi^0$
- $\rightarrow K^- \pi^+ \pi^- \pi^+$
- $\rightarrow K^0_s \pi^+ \pi^-$

$X^-_{had} = n_1\pi^\pm + n_2K^\pm + n_3\pi^0 + n_4K^0_s$

$(n_1=1,..5,\ n_2=0,..2,\ n_3=0,..2,\ n_4=0,1)$

Signal Side

- The recoil of the tag B is referred as the **"signal side"**
- Identify leptonic and major hadronic τ decay modes in the signal side ⇒ ~80% of τ BR.

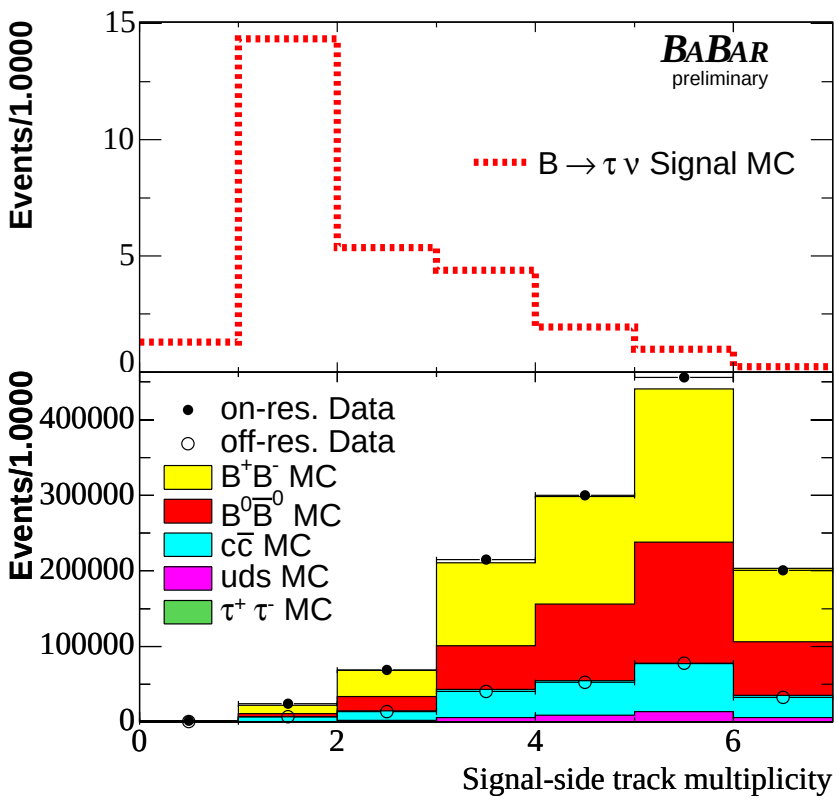


τ decay modes used

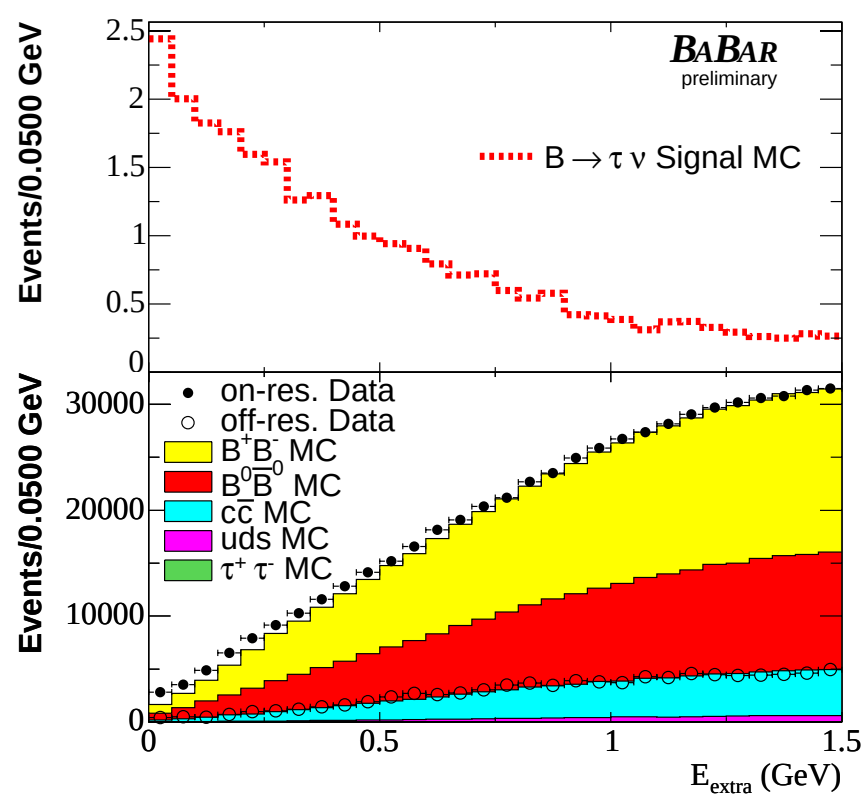
	BR (%)
$\tau \to e\nu\bar{\nu}$	17.84 ± 0.06
$\tau \to \mu\nu\bar{\nu}$	17.36 ± 0.06
$\tau \to \pi\nu$	11.06 ± 0.11
$\tau \to \pi\pi^0\nu$	25.42 ± 0.14
$\tau \to \pi\pi\pi\nu$	9.12 ± 0.10

Signature of $B^+ \to \tau^+ \nu$ Decay in the Signal Side

- $B \to \tau\nu$ decays produce small number of tracks and neutrals.



Number of charged tracks in the signal side



Total energy (GeV) of the signal-side neutrals with E>30 MeV

Three types of tag B are used

- Hadronic B Tags
- $D^0 l\nu X$ Tags ($X=\pi^0$, γ or nothing)
- $D^{*0} l\nu$ Tags **(New)**

Next :

- *Brief overview of the first two methods*
- *Focus on the new analysis method using $D^{*0} l\nu$ tags*

Search for $B^+ \to \tau^+ \nu$ using Hadronic B Tags

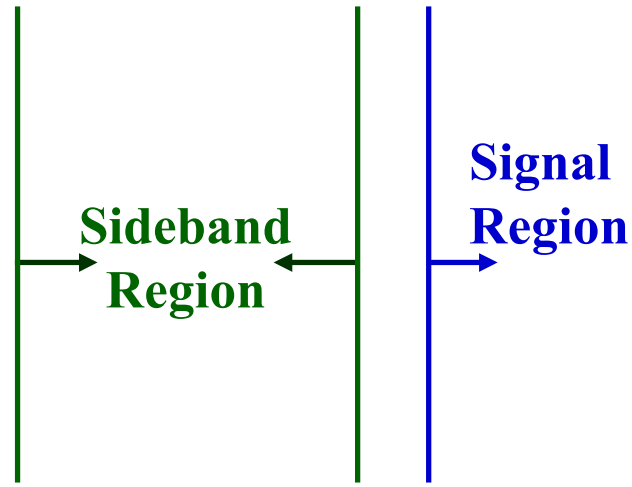
- Tag B reconstructed in a set of hadronic final states

$B^- \to D^{(*)0} X^-_{had}$, $D^{*0} \to D^0 \pi^0$

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

$X^-_{had} = n_1 \pi^\pm + n_2 K^\pm + n_3 \pi^0 + n_4 K^0_s$

$(n_1=1,..5,\ n_2=0,..2,\ n_3=0,..2,\ n_4=0,1)$



$$m_{ES} = \sqrt{\left(E^{*2}_{beam} - P^{*2}_B\right)} \left(GeV/c^2\right)$$

- 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 modes

$\tau \to e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$ and $\tau \to \pi\nu$, $\pi\pi^0\nu$, $\pi\pi\pi\nu$

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±0.4±0.1	2
$\mu\nu\bar{\nu}$	1.9 ± 0.1	0.9±0.5±0.1	0
$\pi\nu$	2.6 ± 0.1	1.3±0.6±0.2	2
$\pi\pi\pi\nu$	0.6 ± 0.1	4.3±1.0±0.3	4
$\pi\pi^0\nu$	2.0 ± 0.1	10.0±1.6±1.3	7
all	10.5±0.2	17.2±2.1±1.3	15

Expect ~1.8 signal events, for $BR(B\rightarrow\tau\nu)=10^{-4}$

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))

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

- Tag side: $D^0 l\nu X$, where $X=\pi^0$, γ or nothing.

  $D^0 \to K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$, $K_s\pi\pi$

- Signal side: $\tau \to (e, \mu)\nu\bar{\nu}$
- Total selection efficiency $(4.19 \pm 0.31_{stat} \pm 0.36_{syst}) \times 10^{-4}$

Branching fraction upper limit

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

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

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

To improve the sensitivity of the search a new analysis is performed using a cleaner subset of the $D^0 l\nu X$ tags.

Search for $B \to \tau\nu$ using $D^{*0}l\nu$ Tags

- Tag B reconstructed in exclusive semi-leptonic decay modes, $D^{*0}l\nu$, a cleaner subset of the $D^0 l\nu X$ tags. ~3.4% of the B^- meson BR

$B^- \to D^{*0}\, l^-\, \nu$ ($l = e, \mu$)

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

- On the signal side, both leptonic and major hadronic τ decay modes are identified $\Rightarrow$ ~80% of τ BR

Signal τ decay modes

$\tau \to e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$

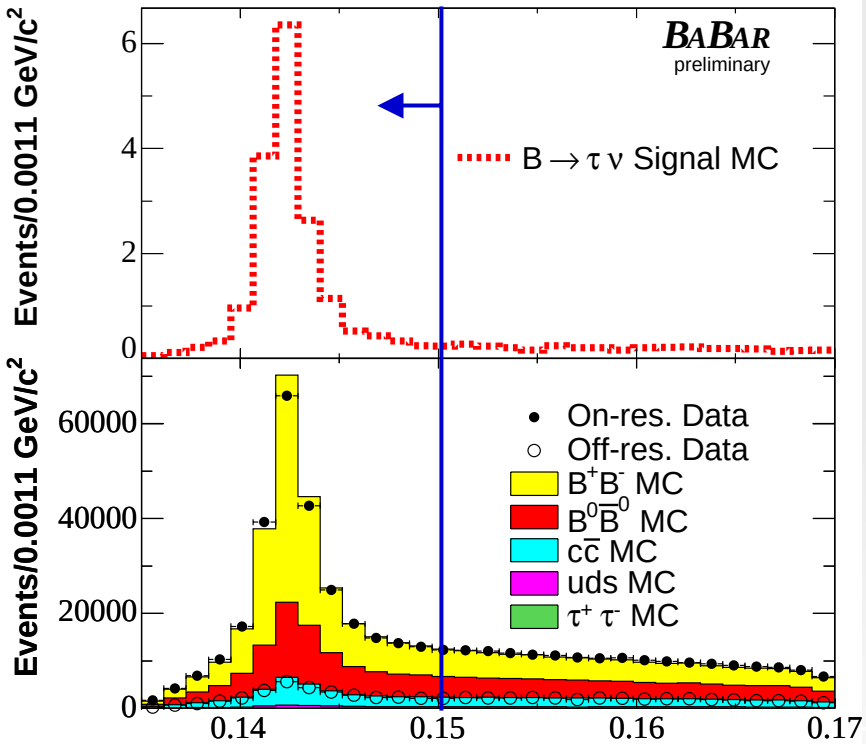
$\tau \to \pi\nu$, $\pi\pi^0\nu$, $\pi\pi\pi\nu$

$D^{*0}l\nu$ Tags : Pros and Cons

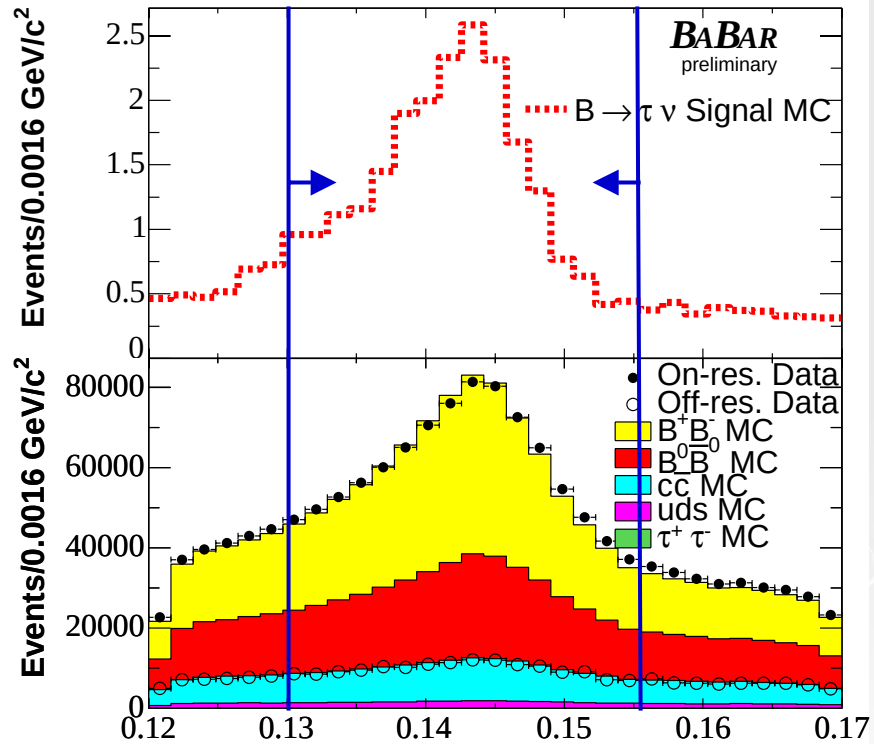
- Disadvantage : reduction of tag B reconstruction efficiency
- Advantages:
  - Cleaner signal side
    - $D^0 l\nu X$: signal-side can contain neutrals from tag B decay
    - $D^{*0} l\nu$: all the neutrals from tag B are removed $\Rightarrow$ improves separation between signal and background
  - Better signal to background ratio in leptonic τ modes
  - Include hadronic τ decay modes $\Rightarrow$ Compensate for the relatively lower tag B reconstruction efficiency
    - $D^0 l\nu X$: hadronic τ modes are not included due to high background level

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

- Mass difference between D^{*0}-D^0 (ΔM) provides strong kinematic constraint.



ΔM (GeV/c^2) for $(D^0\pi^0)e\nu$

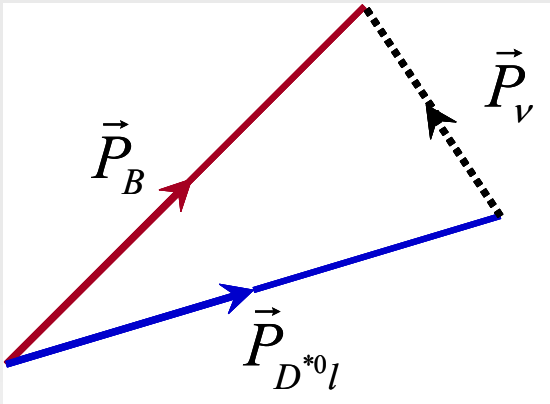


ΔM (GeV/c^2) for $(D^0\gamma)e\nu$

$D^{*0}l\nu$ Tag Reconstruction (Cont')

- Lepton $P^* > 1$ GeV
- Lepton and D^0 daughter tracks satisfy appropriate particle ID
- $-1.1 < \cos\theta_{B,D^{*\circ}l} < 1.1$

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



- Net event charge = 0

$$\varepsilon_{tag} = (\ 1.751 \pm 0.071\ (stat.) \pm 0.053\ (syst.)\ ) \times 10^{-3}$$

$B^+ \rightarrow \tau^+ \nu$ Signal Selection

- Signal τ is identified in one of the six selection modes

  (1) $e\nu\bar{\nu}$

  (2) $\mu\nu\bar{\nu}$

  (3) $\pi\pi\pi\nu$

  (4) $\pi\nu$

  (5) $\pi\pi^0\nu$

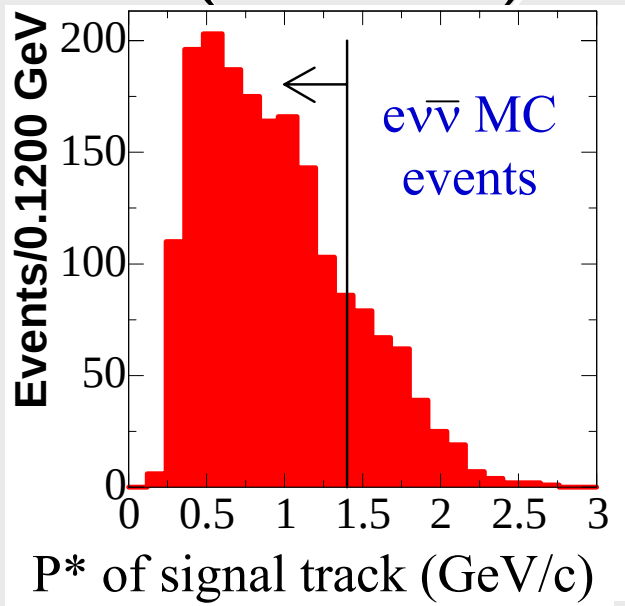
  (6) Failed Particle ID (PID)

- No overlap of events among selection modes

$B^+ \to \tau^+ \nu$ Signal Selection (Cont')

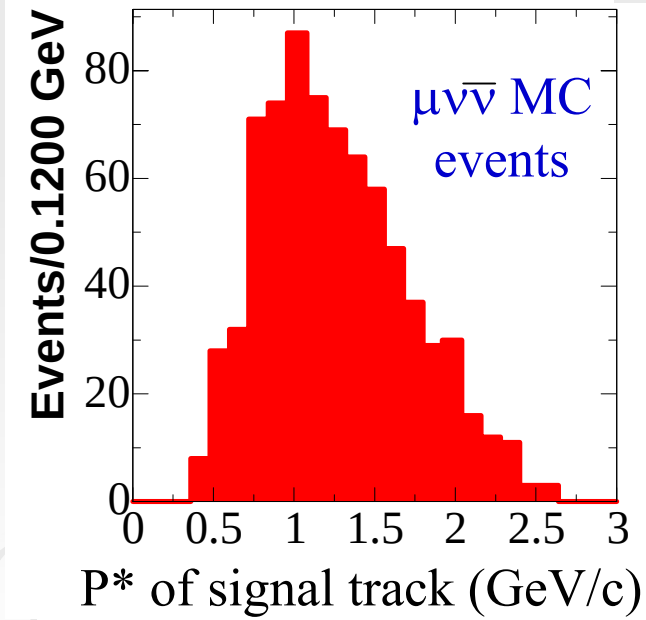
$e\nu\bar{\nu}$ Selection

- One signal-side track
- Signal track satisfies e ID, fails μ and K ID
- P* of e < 1.4 GeV/c



$\mu\nu\bar{\nu}$ Selection

- One signal-side track
- Signal track satisfies μ ID, fails e and K ID
- P* requirement not applied
  - *P* distribution of signal muon satisfying particle ID peaks ~1 GeV/c*



$B^+ \to \tau^+ \nu$ Signal Selection (Cont')

$\pi\pi\pi\nu$ Selection

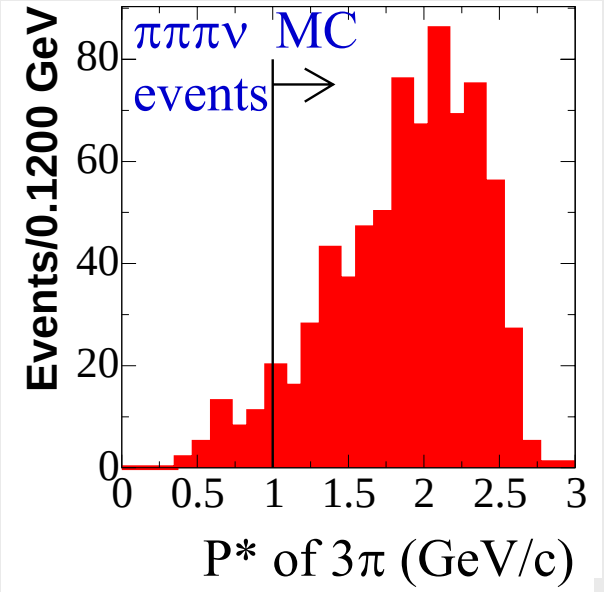
- Three signal-side tracks
- Signal track satisfies π ID, fails e, μ, K ID
- P* of 3π > 1.0 GeV/c.
- Intermediate $a_1^{\pm}$ resonance

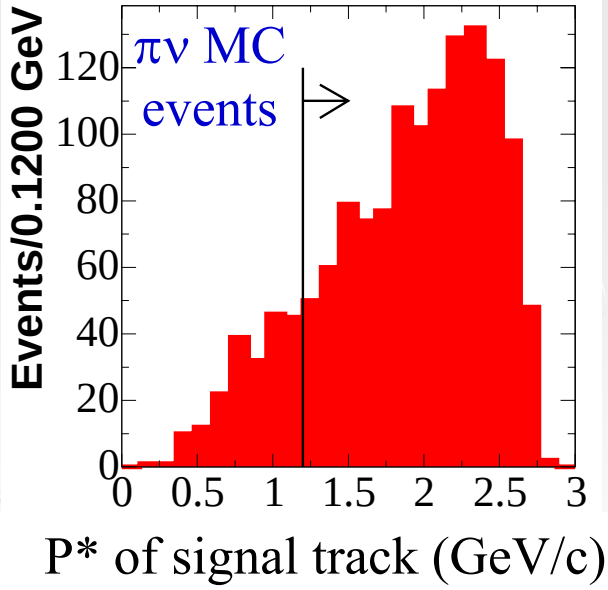
$\pi\nu$ Selection

- One signal side track
- No signal-side π^0
- Signal track fails e, μ and K ID
- Signal track P*>1.2 GeV/c

$\pi\pi^0\nu$ Selection

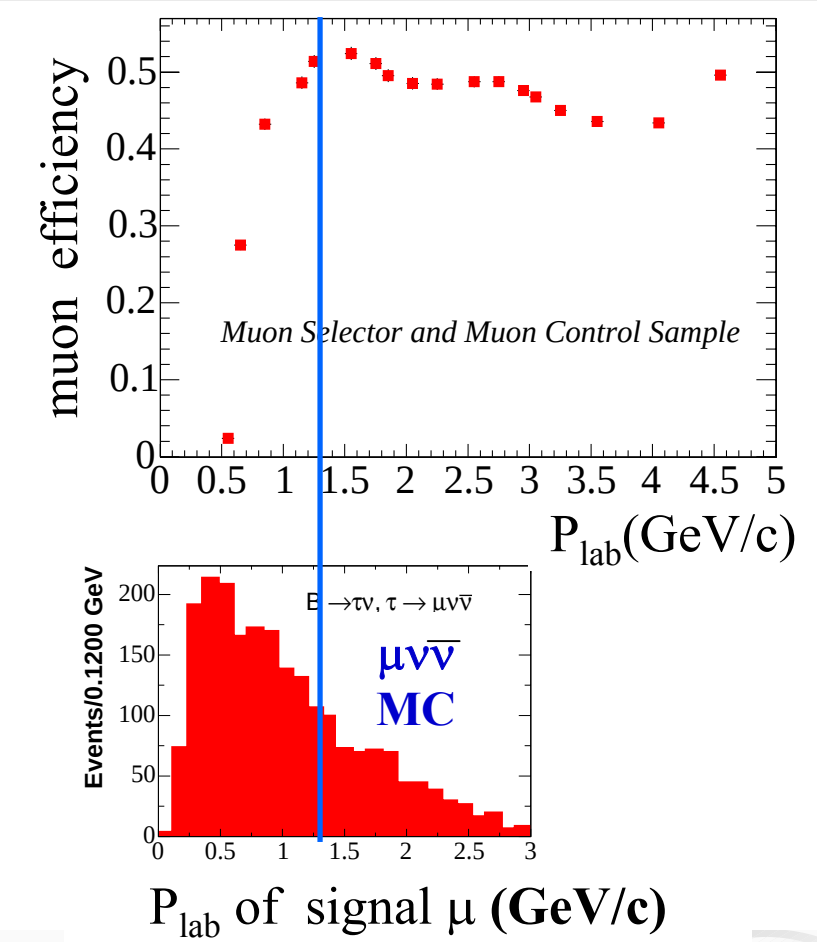
- One signal side charged track
- At least one signal-side π^0
- Signal track fails e, μ and K ID
- Intermediate $\rho^{\pm}$ resonance





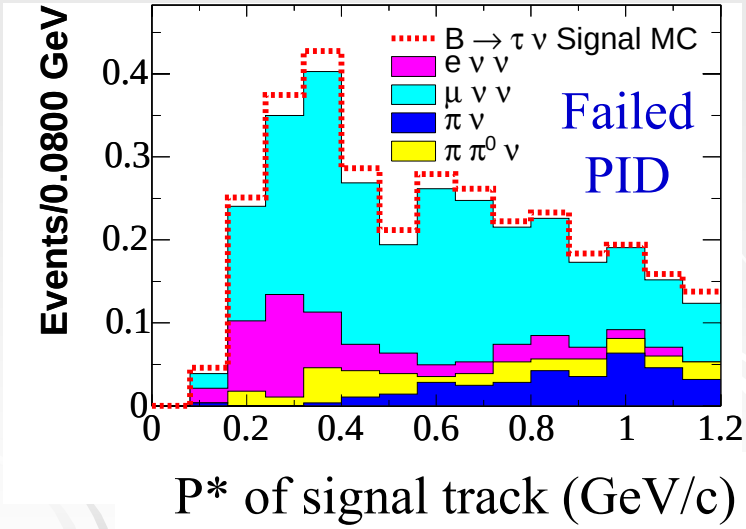
$B^+ \to \tau^+ \nu$ Signal Selection (Cont')

- Low muon identification efficiency for muons from $\mu\nu\bar{\nu}$



Failed PID Selection

- One signal side track
- No signal-side π^0
- Signal track fails e, μ and K ID
- Signal track P*<1.2 GeV/c

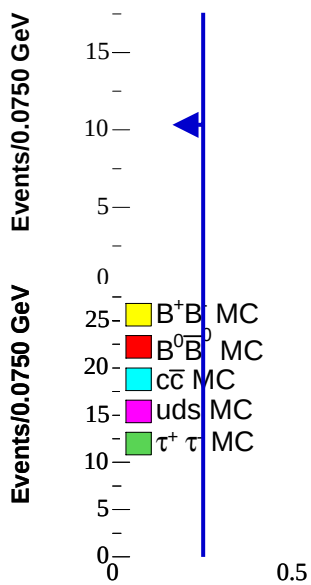


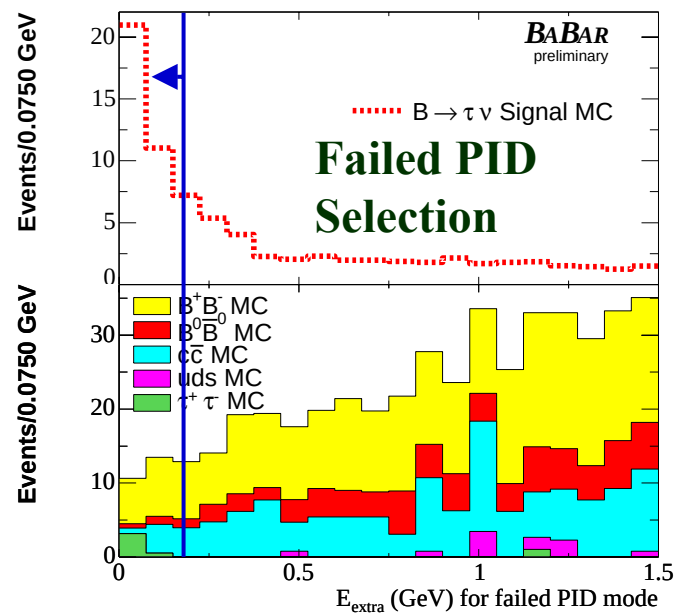
$B^+ \to \tau^+ \nu$ Signal Selection (Cont')

- Signal defining quantity : $E_{extra} = \Sigma\, E_{Neutral}$ (>30MeV)

$E_{Neutral}$ is the lab energy of any neutral, not associated with the tag B or the signal side ($\tau \to \pi\pi^0\nu$ selection).

- *E_{extra} in signal : beam-background, hadronic split-offs, bremsstrahlung etc*
- *Blinding applied to E_{extra}<0.35 GeV region in on-peak data*





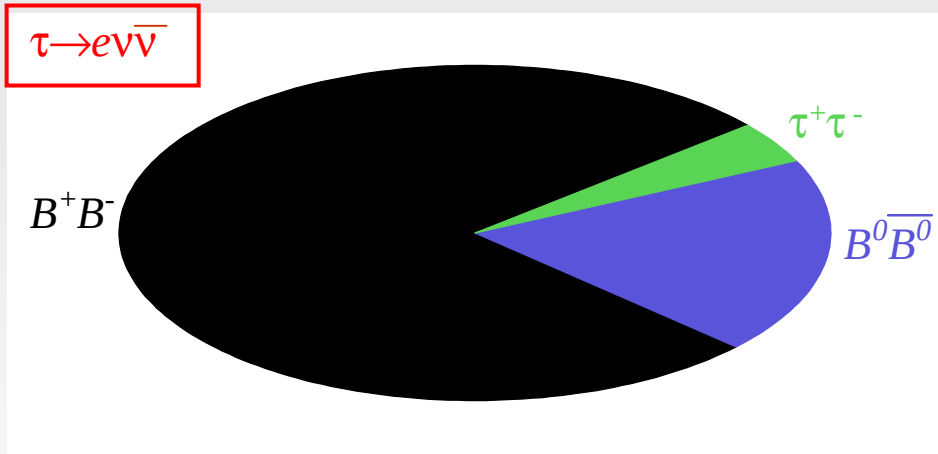
E_{extra} (GeV)	$e\nu\bar{\nu}$	$\mu\nu\bar{\nu}$	$\pi\nu$	$\pi\pi^0\nu$	$\pi\pi\pi\nu$	Failed PID
Signal Region	< 0.25	< 0.15	< 0.30	< 0.25	<0.20	< 0.17

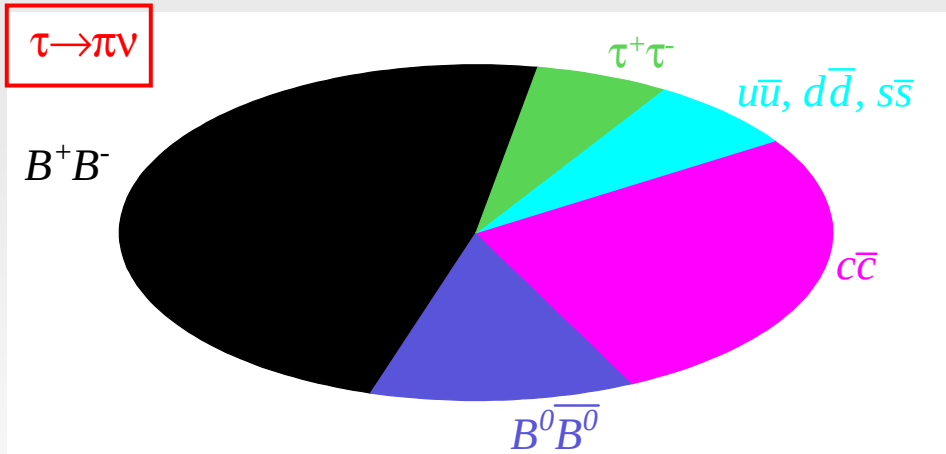
Background

- Main source of background is B^+B^-

Tag B correctly reconstructed, Undetected particles on the signal side : K_L and/or neutrino, frequently tracks and (or) neutrals pass outside detector acceptance.

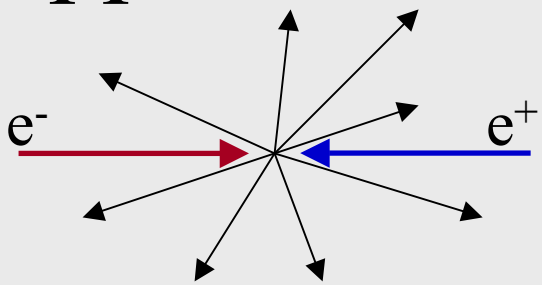
- Continuum events ($e^+e^- \rightarrow u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, $\tau^+\tau^-$) in hadronic τ modes



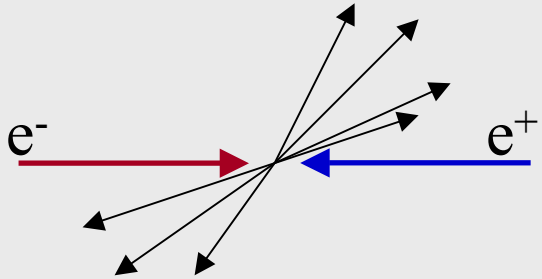


Continuum Background Suppression

- Continuum background jet-like, $B\bar{B}$ events isotropic
- Event shape variables
  - Fox Wolfram moment
  - $\cos\theta_T$: *Cosine of the angle between the thrust axis of tag B and the thrust axis of the signal side*



B decays (CM): isotropic

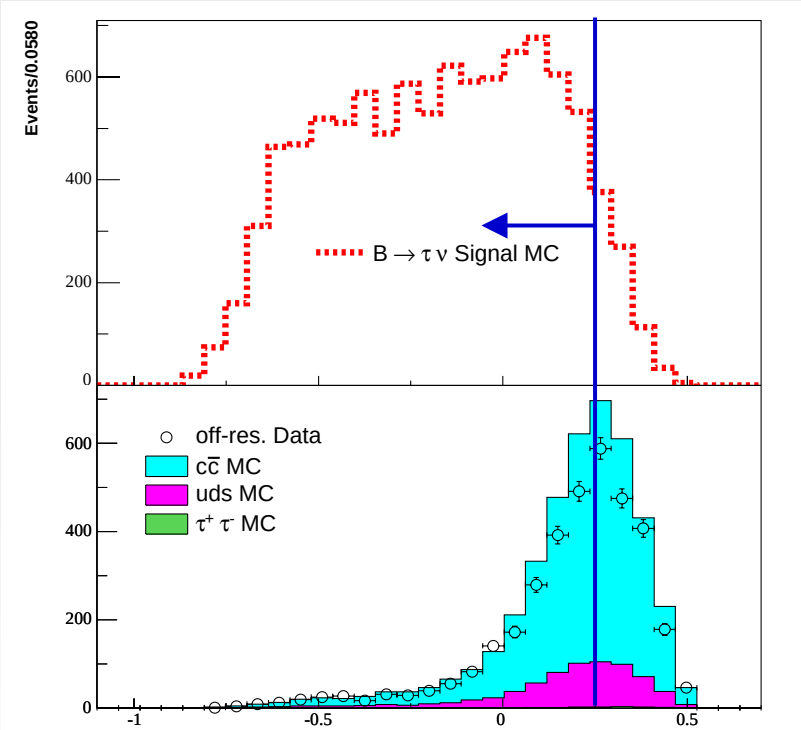


Continuum (CM): jet-like

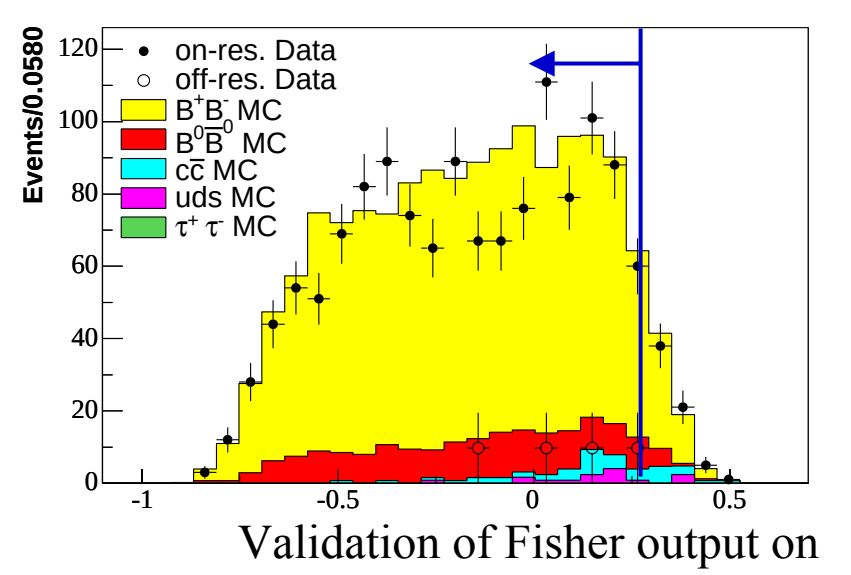
- Kinematic variables for continuum suppression
  - P^* of the D^{*0}
  - P^* of the primary lepton
  - $\cos\theta_{B,D^{*0}l} = \dfrac{\left(2E_B E_{D^{*0}l} - m_B^2 - m_{D^{*0}l}^2\right)}{2\left|\vec{p}_B\right|\left|\vec{p}_{D^{*0}l}\right|}$

Continuum Background Suppression (Cont')

- Two event shape variables and three kinematic variables are combined in a Fisher.
- Selects 93% of signal, rejects ~37% of continuum background



Fisher output



Validation of Fisher output on "double-tag" control sample

Signal-Side Selection Efficiency

Decay in MC	Selection efficiency (%)					
	$e\nu\bar{\nu}$	$\mu\nu\bar{\nu}$	$\pi\nu$	$\pi\pi^0\nu$	$3\pi\nu$	Failed PID
$e\nu\bar{\nu}$	43.4	0	1.3	0.2	0	6.9
$\mu\nu\bar{\nu}$	0.1	18.0	8.0	0.6	0	30.4
$\pi\nu$	0	0.3	40.2	1.6	0	8.1
$\pi\pi^0\nu$	0	0	5.2	7.3	0	2.6
$\pi\pi\pi\nu$	0	0	0	0	18.1	0.7
$\pi\pi^0\pi^0\nu$	0	0	0.5	1.7	0	0.2
$\pi\pi\pi\pi^0\nu$	0	0	0	0	2.0	0.3
Other	1.3	1.1	3.4	1.6	1.0	4.1
Total (ε_i)	7.6	3.2	7.5	2.5	1.3	8.3
$\Sigma\varepsilon_i$	30.4					

- Account for cross-feed among modes
- Total signal-side efficiency for each selection

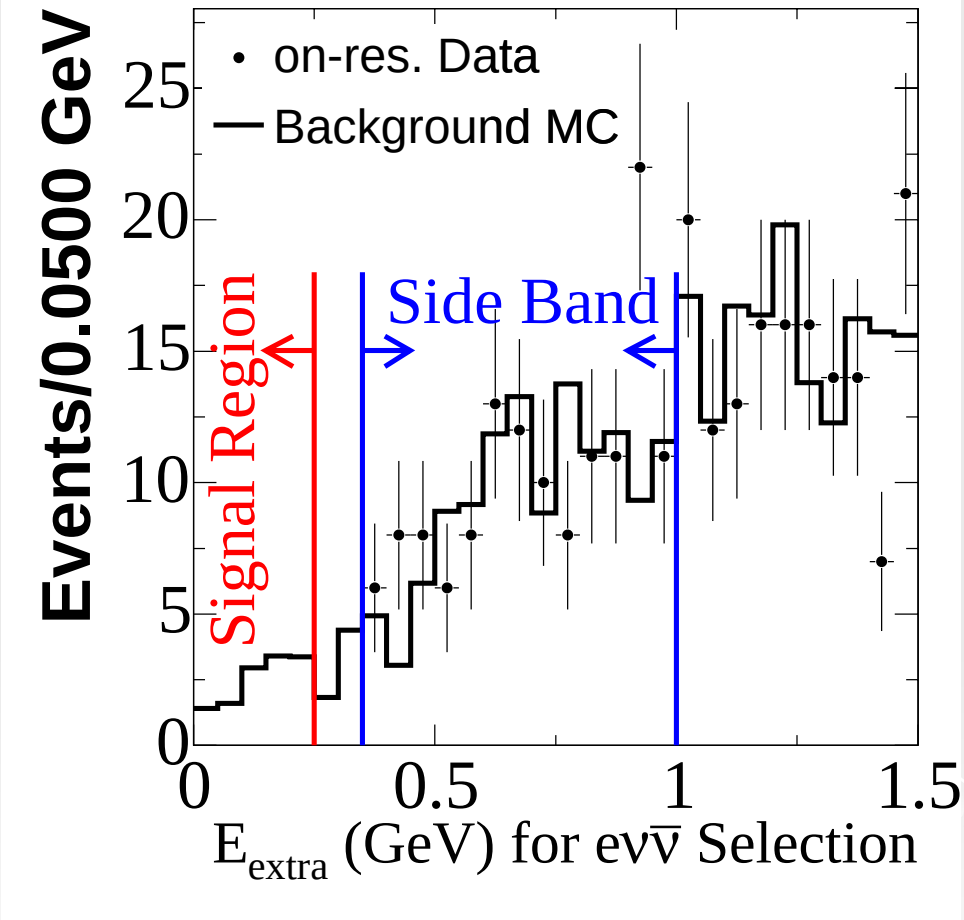
$$\varepsilon_i = \sum_{j=1}^{n_{decay}=8} \varepsilon_i^j f_j$$

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

No systematic correction applied to efficiencies listed in the table

Background Estimation

- E_{extra} side band:
  $0.35 < E_{extra} < 1.0$ GeV
- Count data events in E_{extra} side band
- Extrapolate to the signal region, using the E_{extra} shape from MC.



$$N^{Expected}_{Signal\ region} = N^{data}_{Side\ band} \times \left(N^{MC}_{Signal\ region} / N^{MC}_{Side\ band} \right)$$

Background Estimation (Cont')

Selection Mode	Data sideband extrapolation	Bkg. MC	B^+B^-	$B^0\overline{B}^0$	udscτ	Exp. Sig. $BR(B\to\tau\nu)=10^{-4}$	Bkg./ Sig.
$e\nu\overline{\nu}$	12.8±2.3	11.7±1.7	8.6±1.4	2.6±0.8	0.5±0.5	3.3	3.9
$\mu\nu\overline{\nu}$	5.3±1.4	4.8±1.1	3.7±1.0	1.1±0.5	0	1.4	3.8
$\pi\nu$	26.4±4.7	22.8±3.0	12.0±1.7	4.5±1.1	6.3±2.2	3.3	8.0
Failed PID	30.8±4.6	25.4±3.2	14.3±1.9	2.1±0.7	9.0±2.5	3.7	8.3
$\pi\pi^0\nu$	25.3±3.7	25.2±3.2	15.0±1.9	2.4±0.8	7.8±2.5	1.1	23.0
$\pi\pi\pi\nu$	20.5±2.8	22.9±2.7	12.7±1.8	7.2±1.4	3.1±1.5	0.6	34.2

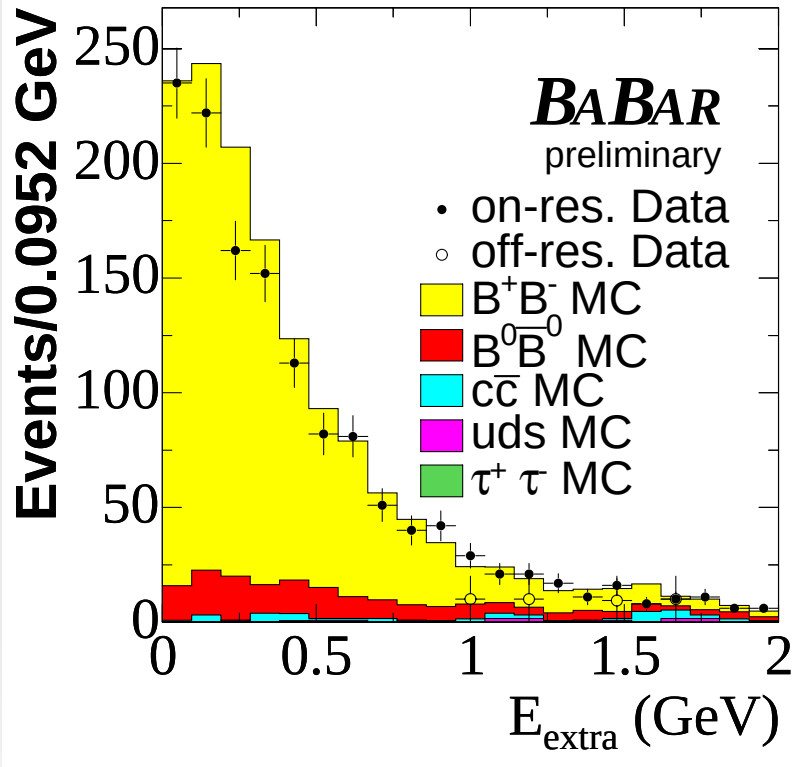
No systematic correction is applied. All errors are statistical only.

Validation of E_{extra} Simulation : Signal MC

- Validate E_{extra} simulation in the signal MC using **"double-tags"**

$$B^- \to D^{*0}\ell^-\bar{\nu}_\ell \oplus B^+ \to \bar{D}^{*0}\ell^+\nu_\ell$$

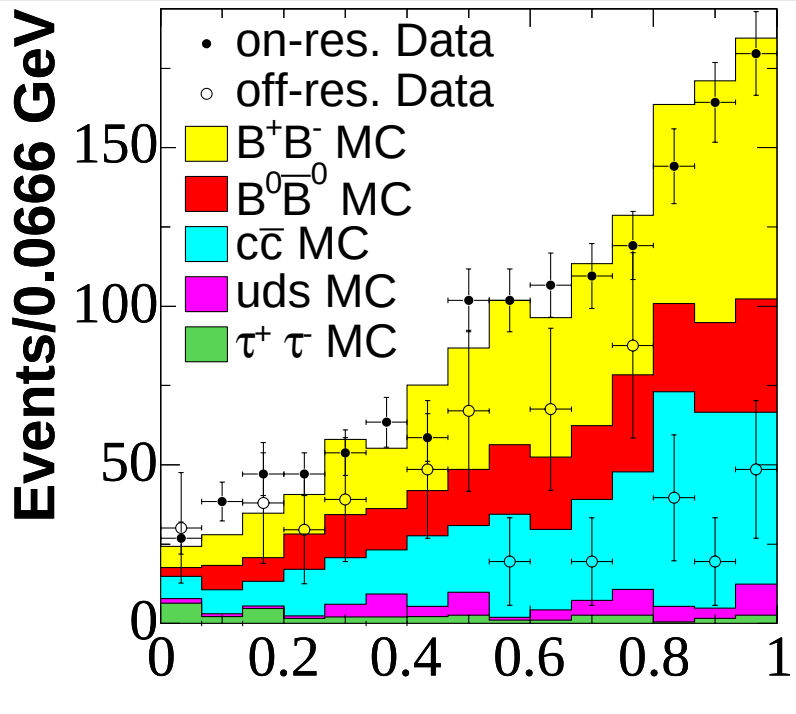
- Double tagged events
  - Reconstruction of the entire event
  - Sources of neutrals contributing to E_{extra} in the double-tag are similar as those in the signal MC



- Reasonable data-MC agreement in E_{extra} distribution for double-tagged events ⇒ validate the simulation of beam-background, hadronic split-offs, bremsstrahlung etc. in the signal MC

Validation of E_{extra} Simulation: Background Estimation

- E_{extra} shape from MC is used for background estimation
- Apply background estimation method on control samples:
  - *Events outside ΔM selection region*
  - *Events with two signal side tracks*
  - *Events with non-zero net charge*
- Good agreement between expected and observed number of events



E_{extra} (GeV) for events outside ΔM selection region containing one signal-side track

Systematic Uncertainties

- Estimation of B^+B^- events in the data sample (1.1%)
- Uncertainties in signal efficiency determination
  - Tag B reconstruction efficiency (2.9%)
  - Signal-side efficiency for each selection mode
    - From ~2% to ~10%
- Uncertainties in background estimation
    - From ~4% to ~15%

Systematic Uncertainty on Signal-side Efficiency

	Selection Mode	Tracking (%)	PID (%)	E_{extra} (%)	π^0 (%)	Fisher (%)	Total Syst. Error (%)	Correction Factor
MC for 1999 to Jun. 2003 conditions	$e\nu\bar{\nu}$	1.4	0.14	1.3	-	-	1.92	0.97
	$\mu\nu\bar{\nu}$	1.4	2.04	2.4	-	-	3.45	0.93
	$\pi\nu$	1.4	1.37	1.5	-	1.0	2.66	1.06
	Failed PID	1.4	0.97	2.6	-	1.0	3.27	1.08
	$\pi\pi^0\nu$	1.4	0.51	2.0	3.3	1.0	4.26	1.01
	$\pi\pi\pi\nu$	4.2	0.40	2.0	-	1.0	4.77	0.99
MC for Sep. 2003 to 2004 Conditions	$e\nu\bar{\nu}$	1.4	0.28	3.3	-	-	3.60	1.01
	$\mu\nu\bar{\nu}$	1.4	1.66	5.6	-	-	6.01	0.88
	$\pi\nu$	1.4	1.54	3.1	-	1.0	3.87	1.06
	Failed PID	1.4	0.91	5.5	-	1.0	5.83	1.08
	$\pi\pi^0\nu$	1.4	0.43	3.3	3.3	1.0	4.99	1.02
	$\pi\pi\pi\nu$	4.2	0.35	10.2	-	1.0	11.08	1.03

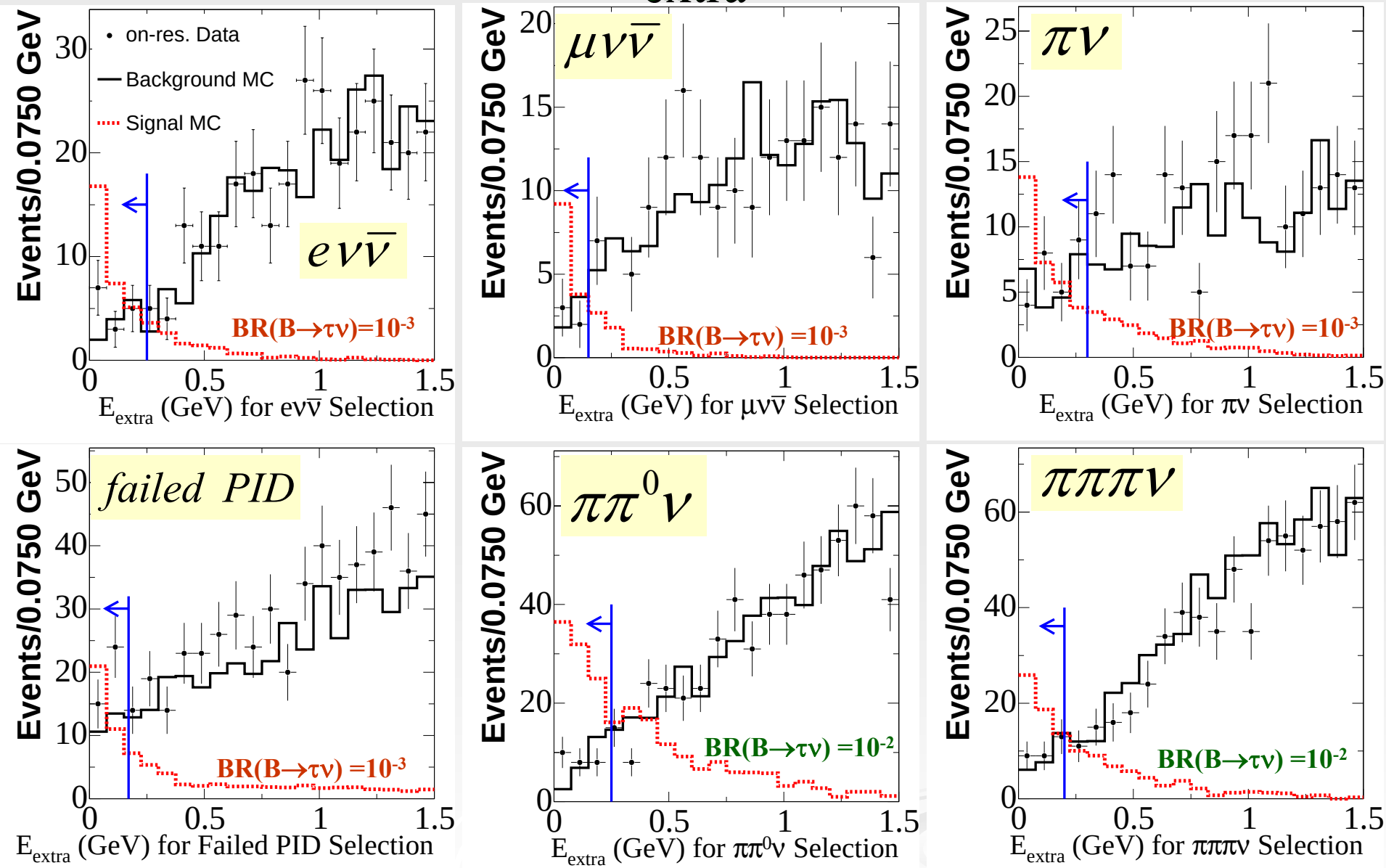
Systematic Uncertainty on Background Estimation

Estimation of expected background events in the signal region depends on modeling of E_{extra} variable in background MC.

	Selection Mode	Correction Factor	Systematic Error (%)
MC for 1999 to Jun. 2003 conditions	$e\nu\bar{\nu}$	1.027±0.036	3.5
	$\mu\nu\bar{\nu}$	1.144±0.106	9.2
	$\pi\nu$	1.045±0.028	2.7
	Failed PID	1.090±0.060	5.5
	$\pi\pi^0\nu$	1.070±0.051	4.8
	$\pi\pi\pi\nu$	1.057±0.036	3.4
MC for Sep. 2003 to 2004 Conditions	$e\nu\bar{\nu}$	1.060±0.071	6.7
	$\mu\nu\bar{\nu}$	1.232±0.185	15.0
	$\pi\nu$	1.054±0.059	5.6
	Failed PID	1.079±0.039	3.6
	$\pi\pi^0\nu$	1.216±0.066	5.4
	$\pi\pi\pi\nu$	1.056±0.041	3.9

Un-blinded E_{extra} Distributions

210.6 fb^{-1}



210.6 fb^{-1}

Physics Results

Mode	Signal-side Efficiencies (ε_i) %	Expected Bkg. Events (N_{exp})	Observed Events in On-peak Data (N_{obs})
$e\nu\bar{\nu}$	(7.49±0.38±0.20)	13.35±2.40	17
$\mu\nu\bar{\nu}$	(2.90±0.22±0.13)	6.17±1.72	5
$\pi\nu$	(7.96±0.40±0.26)	27.69±5.00	26
Failed PID	(8.95±0.43±0.38)	33.36±5.11	45
$\pi\pi^0\nu$	(2.51±0.22±0.11)	28.60±4.30	31
$\pi\pi\pi\nu$	(1.35±0.16±0.10)	21.62±3.01	26

N_{BB}= **(231.8±2.6)×10^6**

ε_{tag}= **(1.751± 0.071 (stat.) ±0.051 (syst.))×10^{-3}**

- *Systematic corrections and errors are incorporated in the efficiencies and background estimations*
- *Dominant systematic errors from background estimations*

Limit Setting Procedure

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

- Using a likelihood ratio estimator to combine different channels :

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

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

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

- Uncertainties on expected backgrounds are included in the likelihood definition by convoluting with a Gaussian $G(b_i, \sigma_{bi})$. (L. Lista, NIM A 517, 360 (2004))

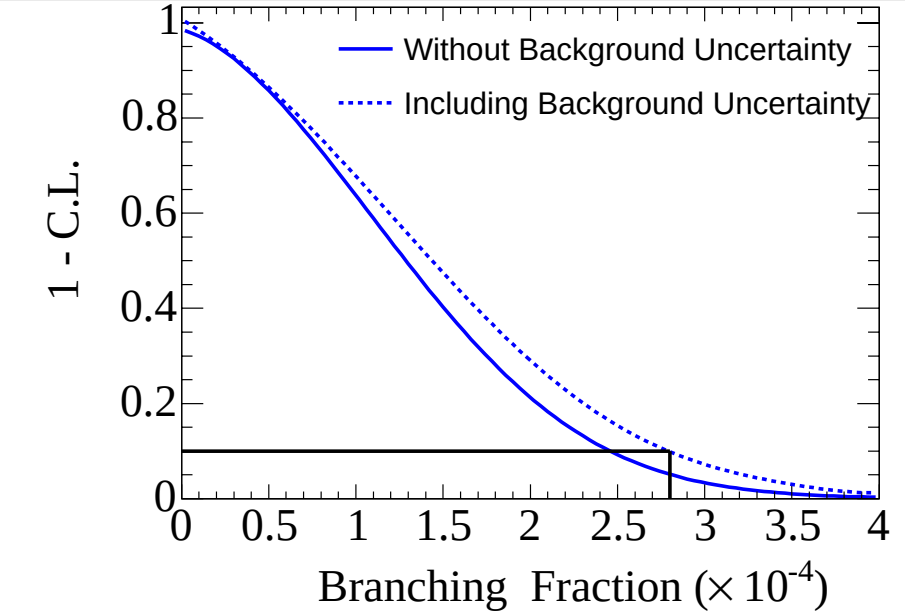
$$L(s_i + b_i) \to L(s_i + b_i) \otimes G(b_i, \sigma_{b_i})$$

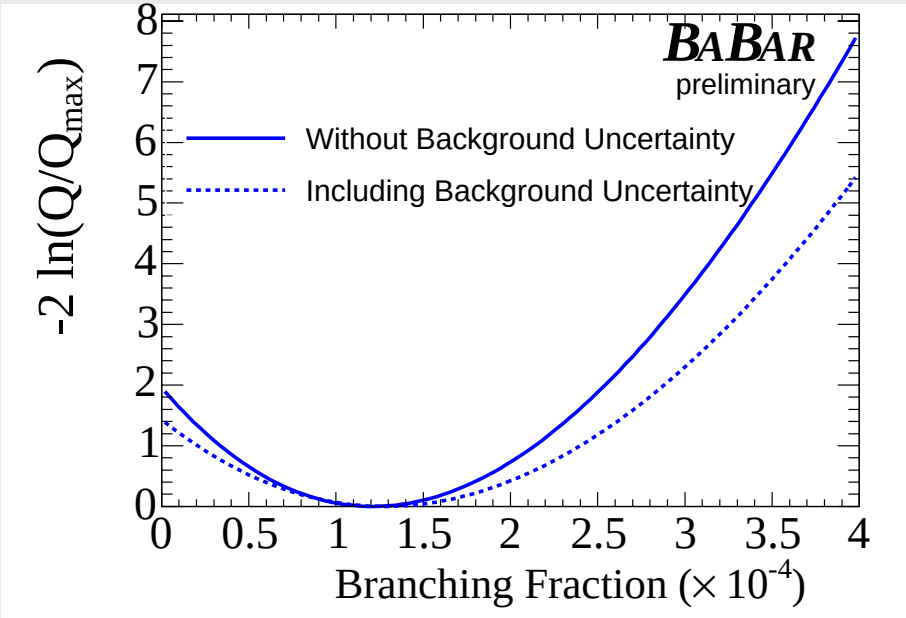
- Branching fraction upper limit calculated by running toy MC for different branching fraction hypothesis.

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

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

Branching Ratio Upper Limit





- Branching fraction upper limit at 90% C.L.

$$\mathbf{BR(B \to \tau\nu) < 2.8 \times 10^{-4}}$$

- Central Value

$$BR(B \to \tau\nu) = 1.28^{+1.15}_{-1.08} \times 10^{-4}$$

Combined Results

- The hadronic tag sample (81.9 fb^{-1}) is statistically independent of the semileptonic $D^{*0}l\nu$ tag sample (210.6 fb^{-1})
- A combined likelihood ratio estimator is created by taking the product of the semileptonic (Q_{sl}) and hadronic (Q_{had}) likelihood ratio estimator: $Q_{comb} = Q_{sl} \times Q_{had}$

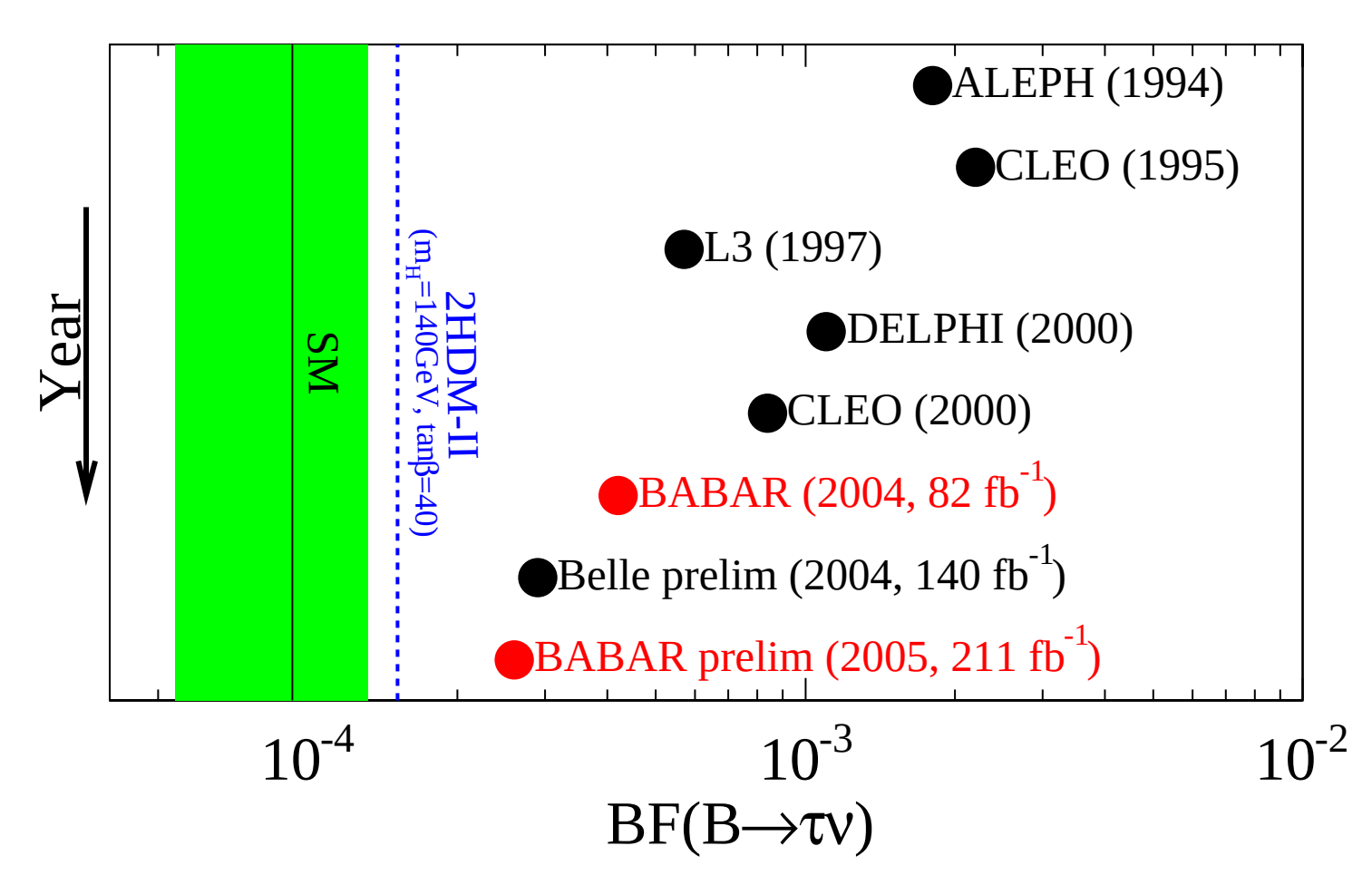
Hadronic Tag and $D^{*0}l\nu$ Tag Samples

$BR(B \to \tau\nu) < 2.6 \times 10^{-4}$ at 90% C.L.

Central Value

$$BR(B \to \tau\nu) = 1.25^{+0.95}_{-0.90} \times 10^{-4}$$

Limit at 90% CL on BR(B→τν) from Different Experiments



Constraint on f_B

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

$f_B < 0.41$ GeV at 90% CL

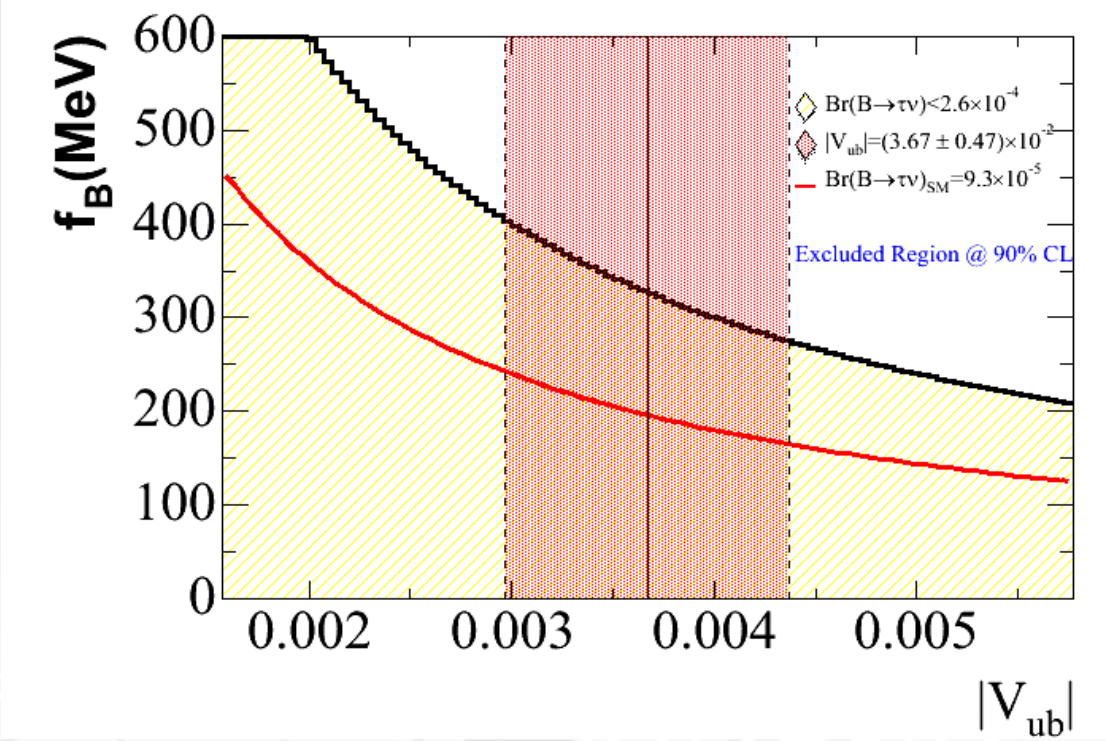
Using PDG 2004 value

$|V_{ub}| = (3.67 \pm 0.47) \times 10^{-3}$

PDG 2004 value

$f_B = (0.196 \pm 0.032)$ GeV

Lattice QCD

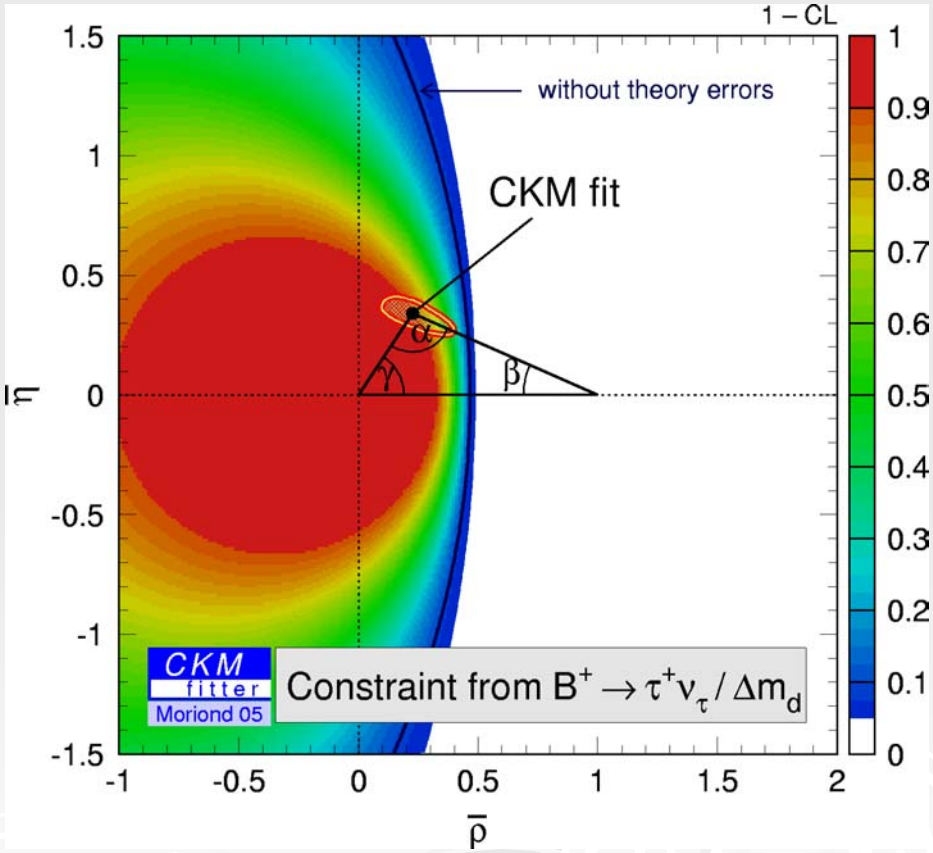


Constraints on CKM Parameters

$$\frac{BR(B \to \tau\nu)}{\Delta m_d} \propto \frac{|V_{ub}|^2}{|V_{td}|^2} = \frac{1}{\left[1-(\lambda^2/2)\right]^2} \cdot \frac{\bar{\rho}^2 + \bar{\eta}^2}{(1-\bar{\rho})^2 + \bar{\eta}^2}$$

$|V_{ub}|^2/|V_{td}|^2 < 0.65$

- Constraint on (ρ,η) from $BR(B\to\tau\nu)/\Delta m_d$ in agreement with the SM
- Current limit not sensitive enough for providing any new constraint in the (ρ,η) parameter space



Analysis by the CKMfitter group (http://ckmfitter.in2p3.fr/)
Courtesy of Andreas Höcker

Constraint on Charged Higgs Mass

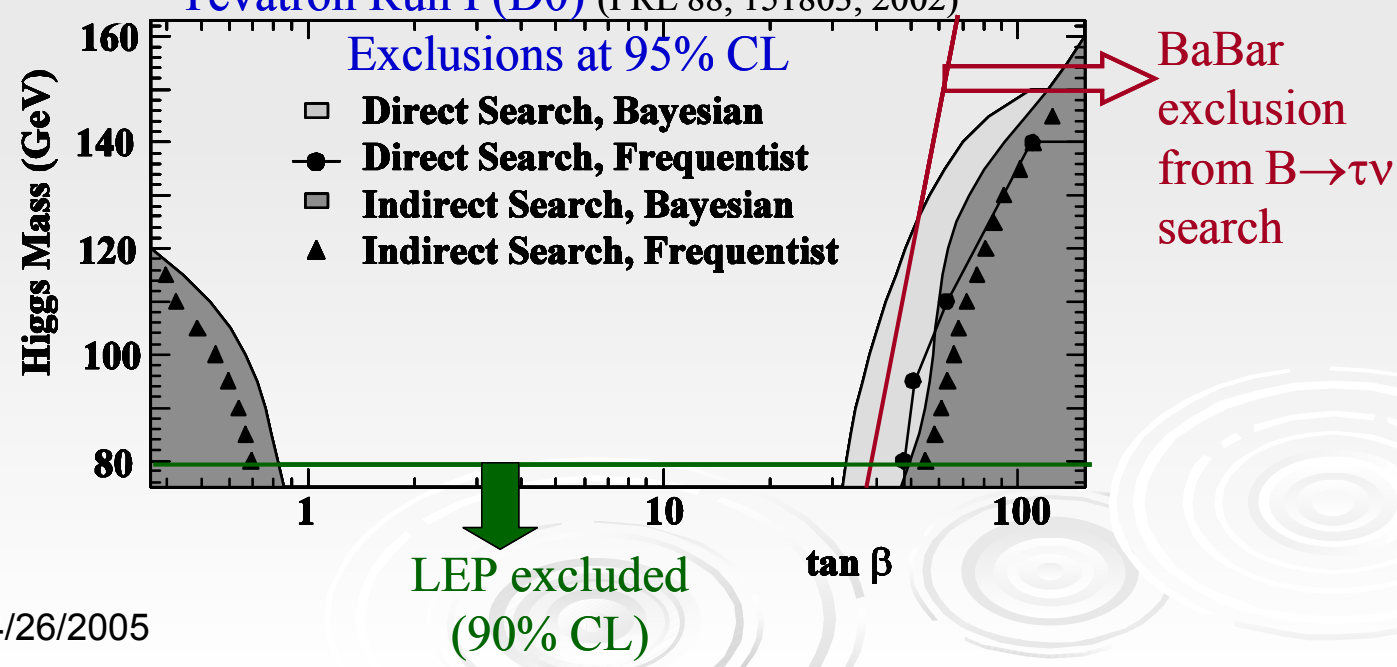
$$BR(B \to \ell\,\nu) = BR_{SM}(B \to \ell\,\nu) \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)^2$$

Two Higgs doublet model (type II)

- Using upper limit on BR(B→τν)

$$\frac{\tan\beta}{m_{H^\pm}} < 0.34\ (GeV/c^2)^{-1}$$

Tevatron Run I (D0) (PRL 88, 151803, 2002)

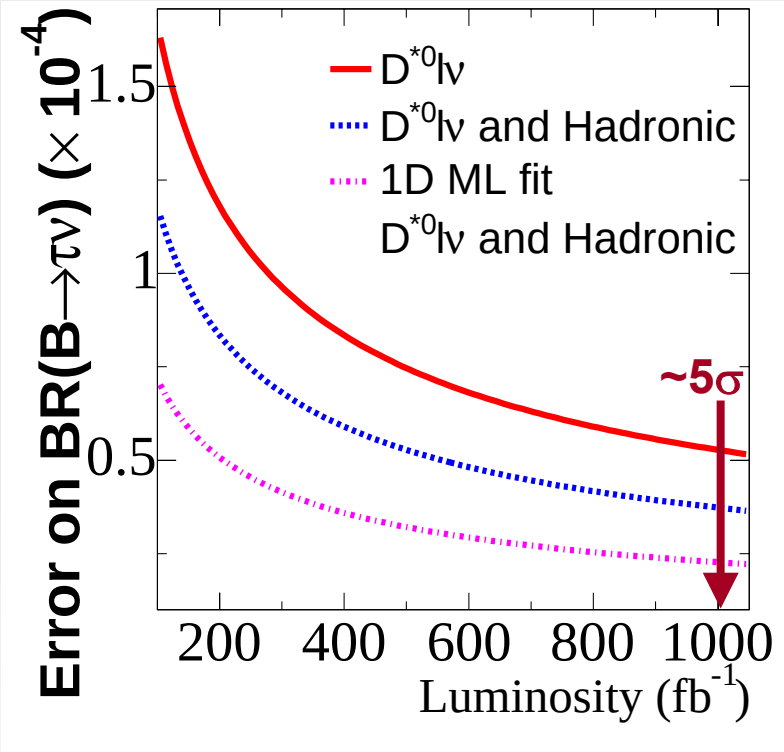


Prospect

- Central value of the branching fraction on 210.6 fb^{-1} using only $D^{*0}l\nu$ tags

$$BR(B \to \tau\nu) = 1.28^{+1.15}_{-1.08} \times 10^{-4}$$

- Investigated the prospect of using 1D likelihood fit on E_{extra}
  - Extract combined branching fraction and background yields
  - **Statistical error on $BR(B\to\tau\nu) \sim 0.70\times10^{-4}$**
    (from toy MC study for $D^{*0}l\nu$ tags at 210.6 fb^{-1} and $BR(B\to\tau\nu)=10^{-4}$)
- Expect similar sensitivity for hadronic tag analysis



The ML fit is currently not applied ⇒ not enough statistics for reliably model the background shapes

Summary

- Search for $B \to \tau\nu$ decay using $D^{*0}l\nu$ tags (on 210.6 fb^{-1}) performed. Branching fraction upper limit at 90% C.L.

$$\mathbf{BR(B \to \tau\nu) < 2.8 \times 10^{-4}}$$

- Combined with statistically independent BaBar analysis for $B \to \tau\nu$ search using hadronic tags (at 81.9 fb^{-1}). Upper limit at 90% C.L:

$$\mathbf{BR(B \to \tau\nu) < 2.6 \times 10^{-4}}$$

  Results are presented at Moriond EW 2005

- The most stringent upper limit so far.
- Constraints on f_B, $|V_{ub}|/|V_{td}|$ and charged Higgs parameters are obtained from the BR upper limit.

BACKUP SLIDES

Branching Fraction Upper Limit

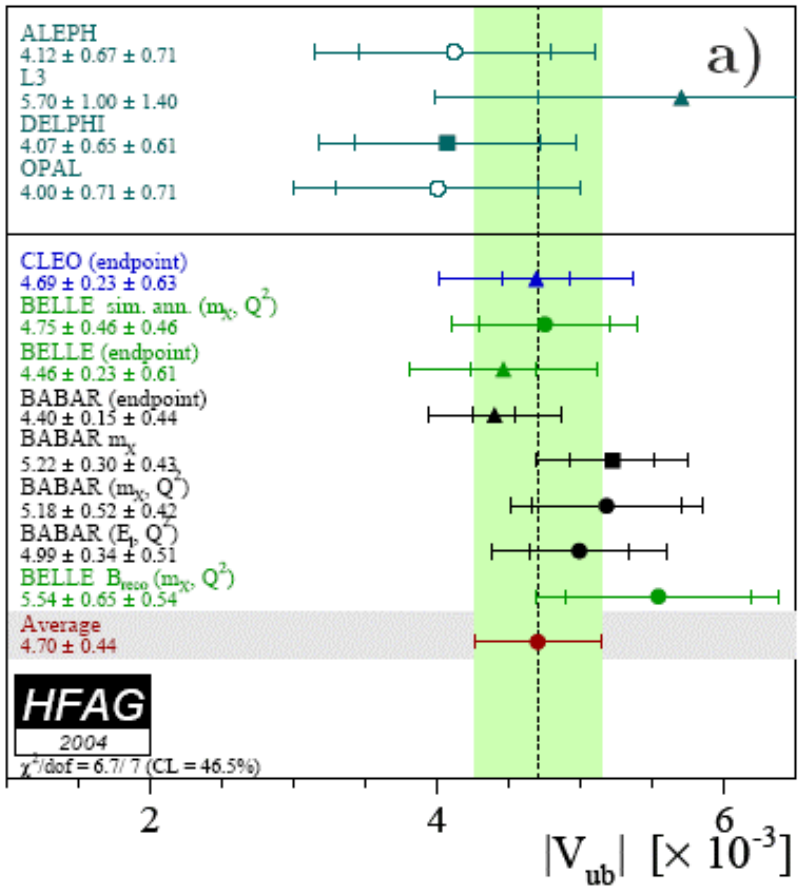
Mode	Expected Bkg. Events (N_{exp})	Observed Events in On-peak Data (N_{obs})	UL on BR at 90% C.L. ($\times 10^{-4}$)	
			$N_{obs}=N_{exp}$	On-peak Data
$e\nu\bar{\nu}$	13.35±2.40	17	2.8	4.0
$\mu\nu\bar{\nu}$	6.17±1.72	5	5.8	5.0
$\pi\nu$	27.69±5.00	26	4.4	3.9
Failed PID	33.36±5.11	45	4.1	7.3
$\pi\pi\nu$	28.60±4.30	31	14.3	16.3
$\pi\pi\pi\nu$	21.62±3.01	26	16.3	21.3
Combined	-	-	1.8	2.8

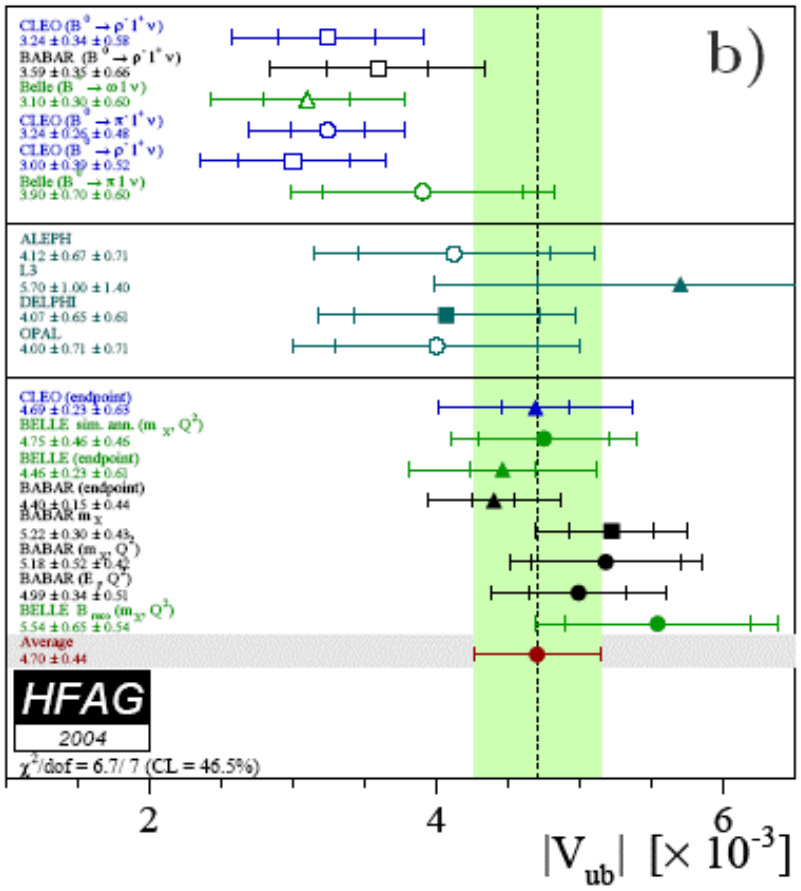
Combination of Modes	UL (90% CL), On-peak Data
$e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$	3.1
$e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi\nu$	2.4
$e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi\nu$, Failed PID	2.7
$e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi\nu$, $\pi\pi^0\nu$, $\pi\pi\pi\nu$	2.5

Rare Leptonic B Decay Results

Decay Mode	SM Prediction	Predicted Rates in NP Models	Upper Limits from BaBar (at 90% CL)
$B^0 \to e^+e^-$	2.4×10^{-15}		6.1×10^{-8}
$B^0 \to \mu^+\mu^-$	1.0×10^{-10}	$\sim10^{-7}$ (Phys. Rev D 66, 074021 (2002))	8.3×10^{-8}
$B^0 \to e^\pm\mu^\mp$	-		18×10^{-8} PRL (hep-ex/0408096)
$B^+ \to K^+\nu\bar{\nu}$	$3.8^{+1.2}_{-0.6}\times10^{-6}$		5.2×10^{-5}
$B^+ \to \pi^+\nu\bar{\nu}$	$\propto \lvert V_{td}\rvert^2/\lvert V_{ts}\rvert^2$		1.0×10^{-4} PRL (hep-ex/0411061)
$B \to$ Invisible	$\propto (m_\nu/m_{B^\circ})^2$	10^{-6} to 10^{-7} (Phys. Rev. D 65, 015001 (2002))	2.2×10^{-4} PRL **93**, 091802 (2004)
$B^+ \to \mu^+\nu$	4.2×10^{-7}	up to $\times5$ (Phys. Rev. D. 48, 2342 (1993))	6.6×10^{-6} PRL. **92**, 221803 (2004)

V_{ub}



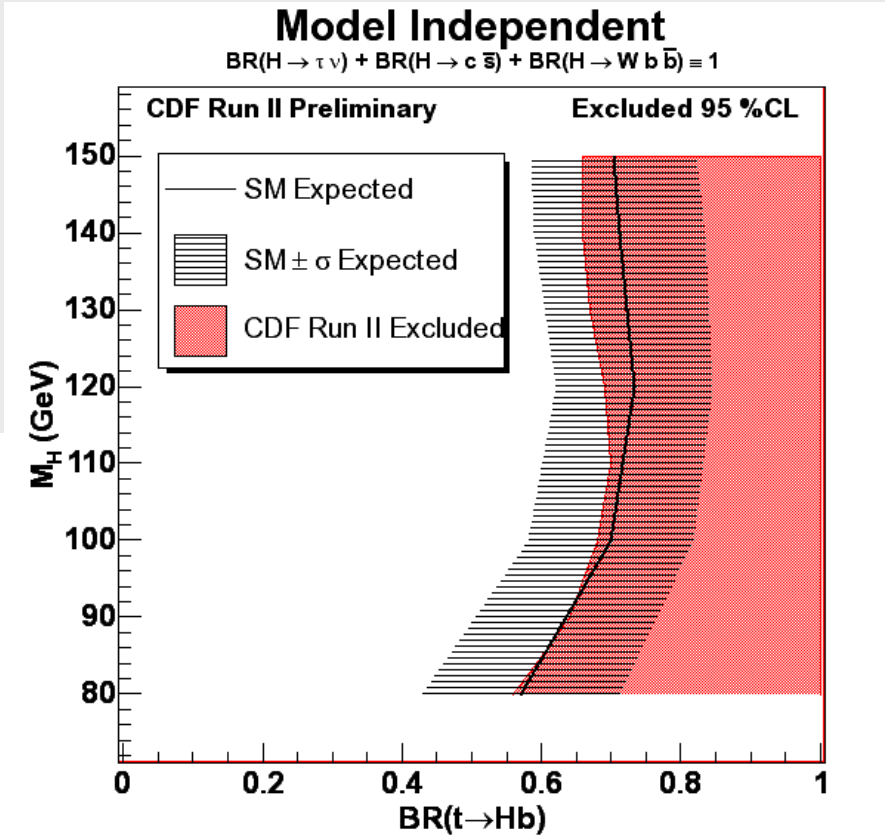


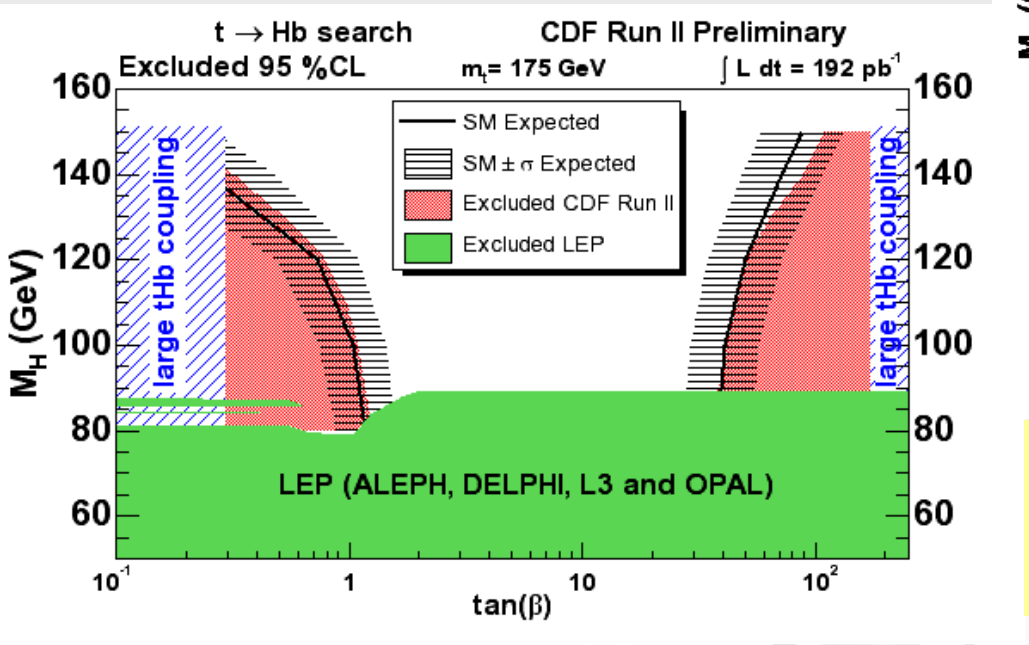
Using WA for V_{ub} : $BR_{SM}(B\rightarrow\tau\nu) = (1.53\pm0.58)\times10^{-4}$

Gervasio Gómez
For the CDF
Collaboration
Moriond EW 2005

Search for H^+

$$\left.\begin{array}{l} \sigma_{tt}^{SM}(th) \\ \varepsilon(t \to Wb + t \to Hb) \\ N^{\text{expected}} \; vs \; N^{obs} \\ L(m, BR(t \to Hb), BR(H \to c\bar{s}, Wb\bar{b})) \end{array}\right\} \Rightarrow$$





$$BR(t \to Hb) < 0.7 \; @ \; 95\% \text{ CL}$$

$$(\text{for } 80 < M_H < 150 \text{ GeV})$$

Rare decays

240 pb^{-1}

95% CL

DØ: $(B_s \rightarrow \mu\mu) < 3.7 \times 10^{-7}$

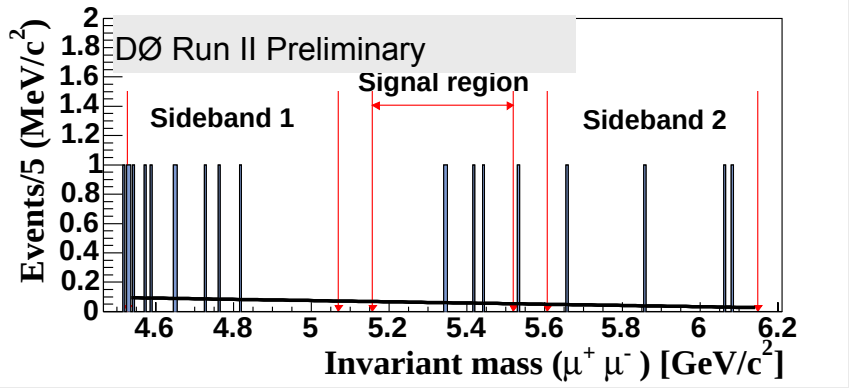
CDF$(B_s \rightarrow \mu\mu) < 2.0 \times 10^{-7}$

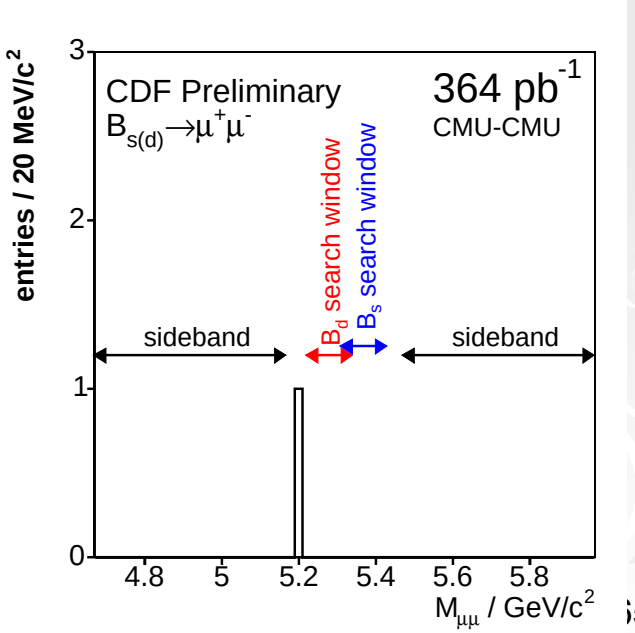
CDF$(B_d \rightarrow \mu\mu) < 4.9 \times 10^{-8}$

World's best limits

CDF new multivariate analysis

No strong MSSM limits from B_s. Too many MSSM parameters



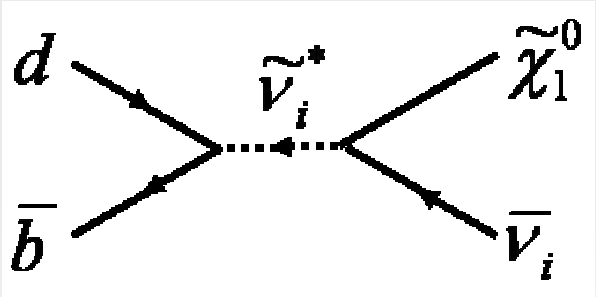


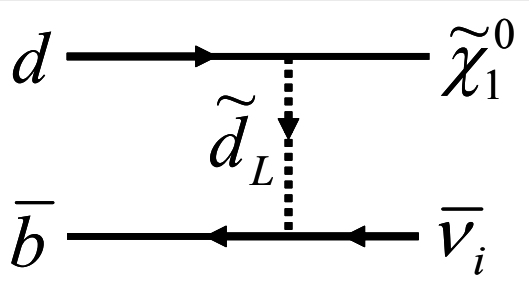
Physics Beyond the SM for $B^0 \rightarrow$ Invisible Decays

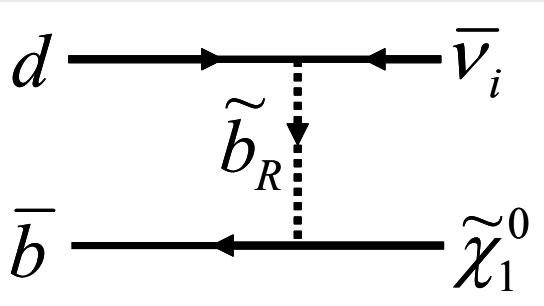
- Enhancement in BR($B^0 \rightarrow$invisible).

  (Phenomenological model motivated by the observation of an anomalous number of dimuon events at the NuTeV experiment, Phys. Rev. D 65, 015001 (2002))

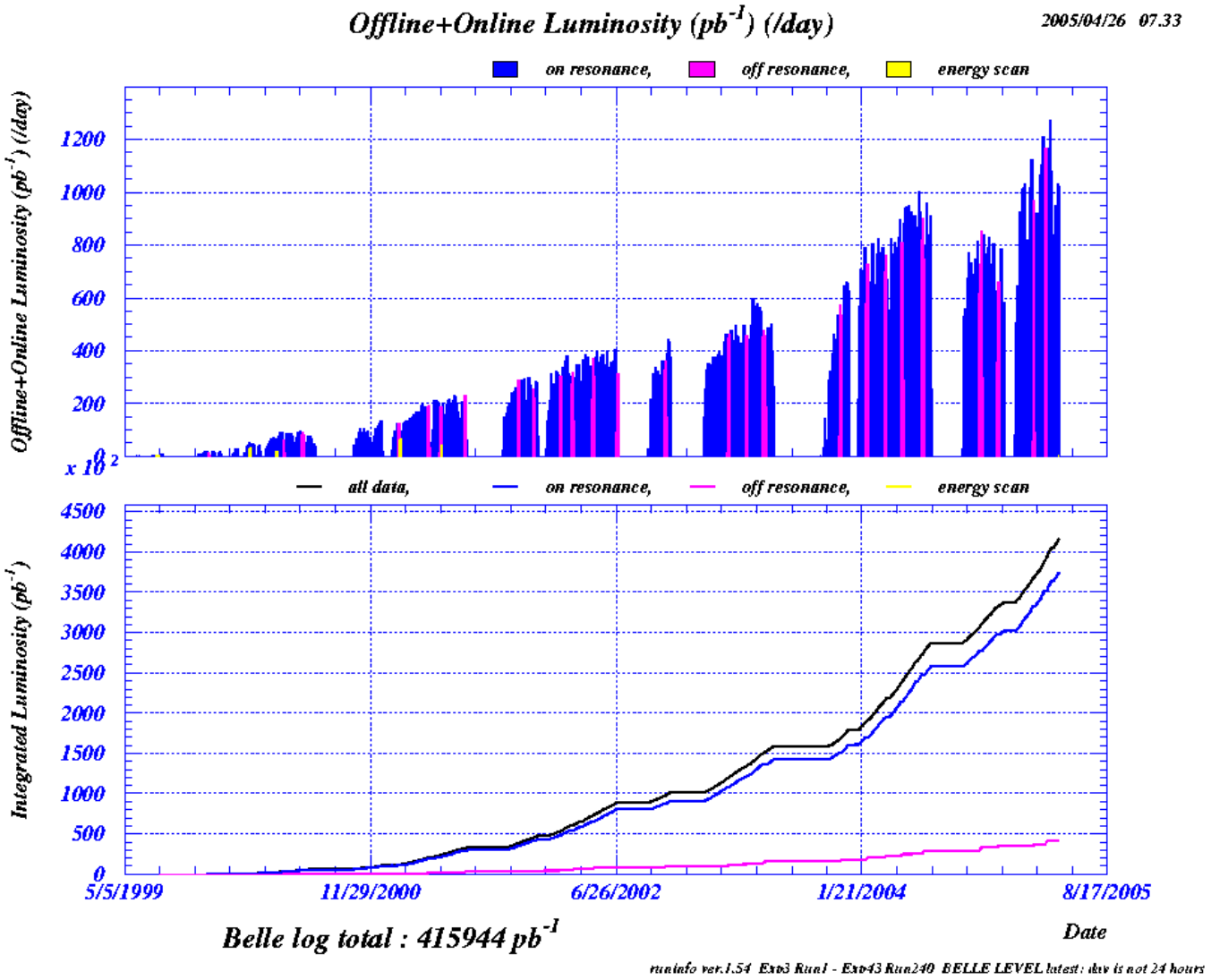
$$BR\left(B^0 \rightarrow \bar{\nu}\chi_1^0\right) \approx 10^{-7} \ \ to \ \ 10^{-6}$$







BaBar: BR(B$\rightarrow$invisible) < 2.2×10^{-4} at 90% CL

(PRL **93**, 091802 (2004))

B-factory Status : Belle