Direct Measurement of $\mathcal{B}(\Upsilon(4S) \rightarrow B^0\overline{B}^0)$

Romulus Godang
University of Mississippi

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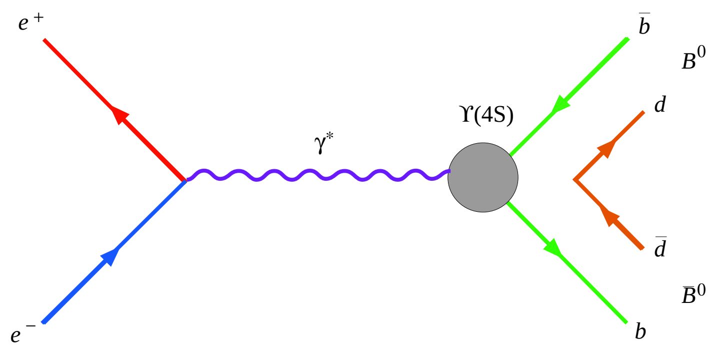
Motivation

$f_{00} \equiv \mathcal{B}(\Upsilon(4S) \to B^0\overline{B}^0)$

$f_{+-} \equiv \mathcal{B}(\Upsilon(4S) \to B^+B^-)$

- Most published papers assume $f_{00} = f_{+-} = 50\%$



- First direct measurement of f_{00}
- Important for B branching fractions
- Significant information to isospin violation in $\Upsilon(4S)$ decays

Theoretical Predictions

- $R^{+/0} \equiv \frac{f_{+-}}{f_{00}} = 1.03 - 1.25$

Authors	$R^{+/0} \equiv \frac{f_{+-}}{f_{00}}$
Atwood et al. (1990)	~ 1.18
Byers et al. (1990)	$1.05 - 1.10$
Lepage (1990)	$1.03 - 1.14$
Kaiser et al. (2003)	$1.04 - 1.25$
Voloshin (2003)	~ 1.19

Soo-hyeon Nam, M. P. Lett. A (2005)

↪ Isospin violation in B decays

↪ Important for CP Violation physics

Experimental Results

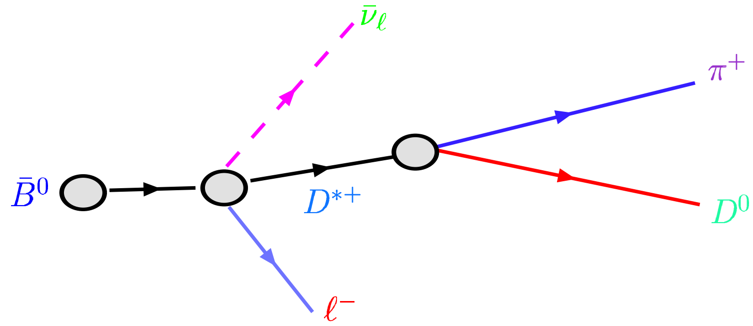
Mode $B \to$	$\int \mathcal{L}dt$	$R^{+/0} \equiv \frac{f_{+-}}{f_{00}}$	Method	Source
$J/\psi K^{(*)(+/0)}$	9.2/fb	$1.04 \pm 0.07 \pm 0.04$	F.R.	CLEO '01
$D^{(*)(+/0)}\ell\bar{\nu}$	2.7/fb	$1.058 \pm 0.084 \pm 0.136$	P.R.	CLEO '02
$J/\psi h^{(+/0)}$	20.7/fb	$1.10 \pm 0.06 \pm 0.05$	F.R.	BABAR '02
Dileptons	29.4/fb	$1.01 \pm 0.03 \pm 0.09$	F.R.	BELLE '03
$J/\psi(K^+/K_s^0)$	81.9/fb	$1.006 \pm 0.036 \pm 0.031$	F.R.	BABAR '04

F.R. = Full Reconstruction P.R. = Partial Reconstruction

- These $R^{+/0}$ measurements mostly depend on
  - Their branching fractions
  - The ratio of B^+ and $\overline{B}^0$ lifetime
  - The assumption of B isospin symmetry
- P.R. yields large event samples compared to F.R.
- We are using P.R. with double-tag technique which does not rely on above assumptions !

Partial Reconstruction

- $\overline{B}^0 \rightarrow D^{*+}\ \ell^-\ \bar{\nu}_\ell\ \ (D^{*+} \rightarrow D^0\ \pi^+)$: D^{*+} is identified by π^+



  - $E_{D^*} \sim \frac{E_\pi}{E_\pi^{cms}} m_{D^*}$
  - $\vec{p}_{D^*} \sim \hat{\vec{p}}_\pi \times \sqrt{E_{D^*}^2 - m_{D^*}^2}$

- Observable Missing Mass Squared

$$\mathcal{M}^2 \equiv (E_{\text{beam}} - E_{D^*} - E_\ell)^2 - (\vec{\mathrm{p}}_{D^*}) + \vec{\mathrm{p}}_\ell^2$$

Only slow π and hard ℓ (e or μ) are detected

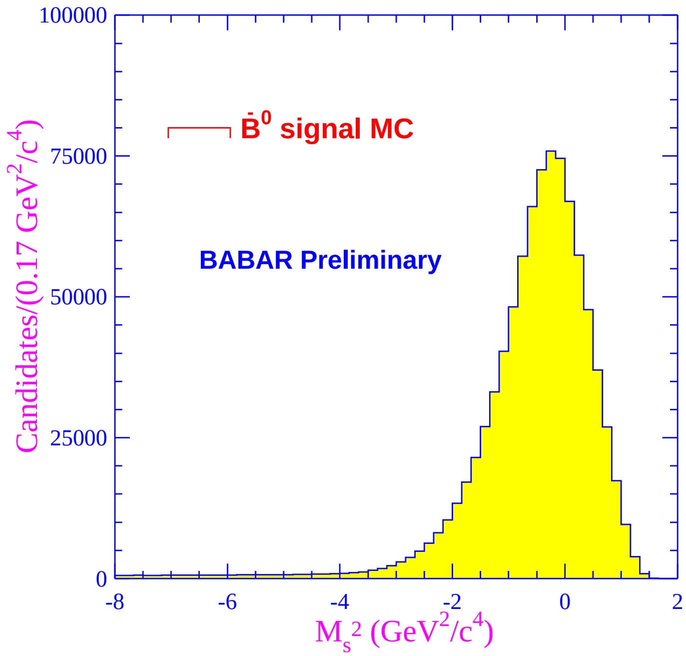
- $1.5\ \mathrm{GeV}/c < p_\ell < 2.5\ \mathrm{GeV}/c$
- $60\ \mathrm{MeV}/c < p_\pi < 200\ \mathrm{MeV}/c$

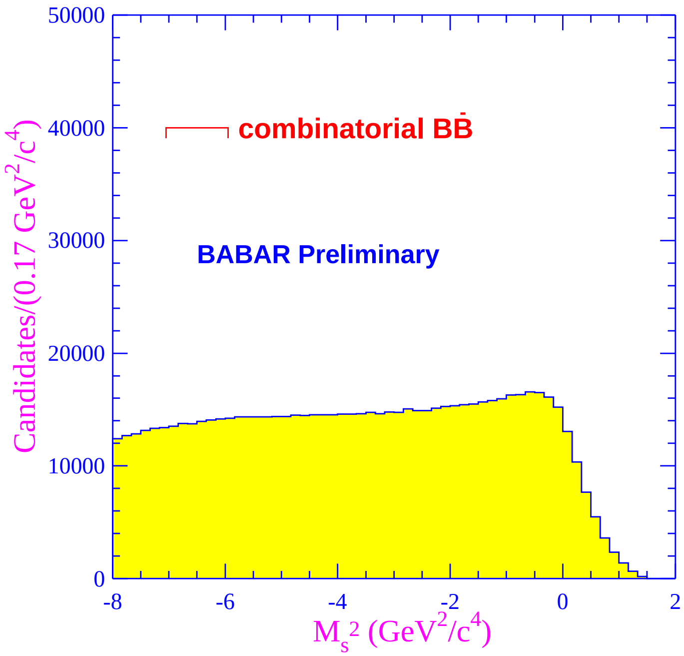
Partial Reconstruction

- With P.R. technique $\Longrightarrow$ $\mathcal{M}^2$ will peak $\sim$ zero

  with background spreads over a wide region

- Observable Missing Mass Squared





- Signal region : $\mathcal{M}^2 > -2.0$ GeV$^2/c^4$

- Sideband : $-8 < \mathcal{M}^2 < -4$ GeV$^2/c^4$

Tag Selection

- Single tags (N_s) $\rightarrow$ at least one neutral B partially reconstructed

  Its missing mass variable $\hookrightarrow \mathcal{M}_s^2$

- Double tags (N_d) $\rightarrow$ both neutral B partially reconstructed

  Its missing mass variables

  - 1^{st} candidate $\hookrightarrow \mathcal{M}_1^2$
  - 2^{nd} candidate $\hookrightarrow \mathcal{M}_2^2$

- BABAR Data

  - 82 fb^{-1} $\Upsilon(4S)$-resonance (mean energy of 10.580 GeV)
  - 10 fb^{-1} off-resonance

f_{00} Determination

The relation of N_s and N_d to $\mathcal{B}$

$$N_s = 2\ N_{B\overline{B}}\ f_{00}\ \epsilon_s\ \mathcal{B}(\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell)$$

$$N_d = N_{B\overline{B}}\ f_{00}\ \epsilon_d\ [\mathcal{B}(\overline{B}^0 \rightarrow D^{*+}\ell^-\bar{\nu}_\ell)]^2$$

where

- $N_{B\overline{B}}$ = total number of $B\overline{B}$
- $\epsilon_s(\epsilon_d)$ = reconstruction efficiency of the single (double) tags

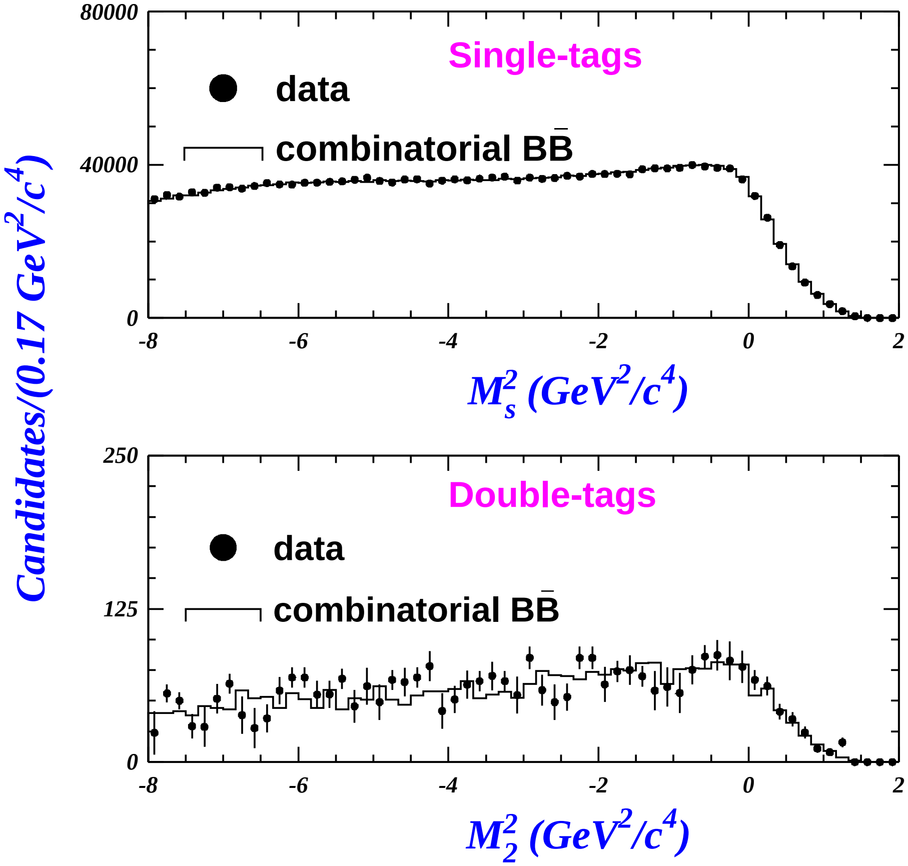
- Define $C \equiv \epsilon_d/\epsilon_s^2 = 0.995 \pm 0.008$ (measured from MC) and solve f_{00}

$$f_{00} = \frac{CN_s^2}{4N_dN_{B\overline{B}}}$$

Backgrounds

- Single & Double Tag Backgrounds
  - **Continuum:** $e^+e^- \longrightarrow \gamma^* \longrightarrow q\overline{q}$
    (subtracted using off-resonance data)
  - **Combinatoric:** random combinations of ℓ and π
    (obtained from MC simulated events)
  - **Peaking:** $B \longrightarrow D^*\pi\ell\bar{\nu}_\ell$, $D^*\pi$ may or may not coming from D^{**}
    (obtained from MC simulated events)
- Additional backgrounds for double tags
  - $\mathcal{M}_1^2$ Combinatoric $(\sim 3\%)$
    1^{st} candidate is combinatoric & 2^{nd} candidate is signal
    (subtracted using $\mathcal{M}_1^2$ sideband data)
  - $\mathcal{M}_1^2$ Peaking $(\sim 1\%)$
    1^{st} candidate is a peaking & 2^{nd} candidate is signal
    (subtracted using MC simulated events)

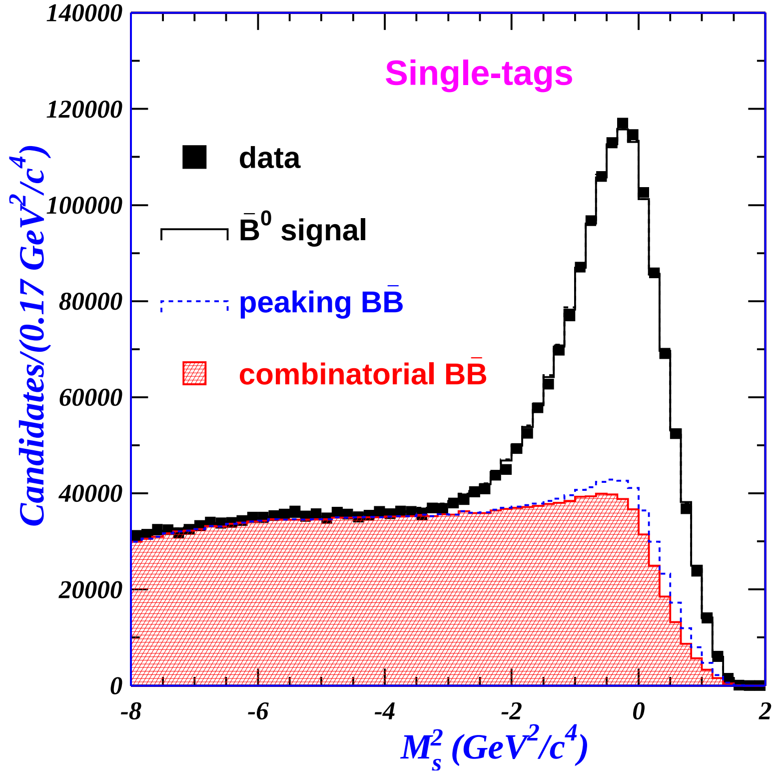
Same-charge Samples



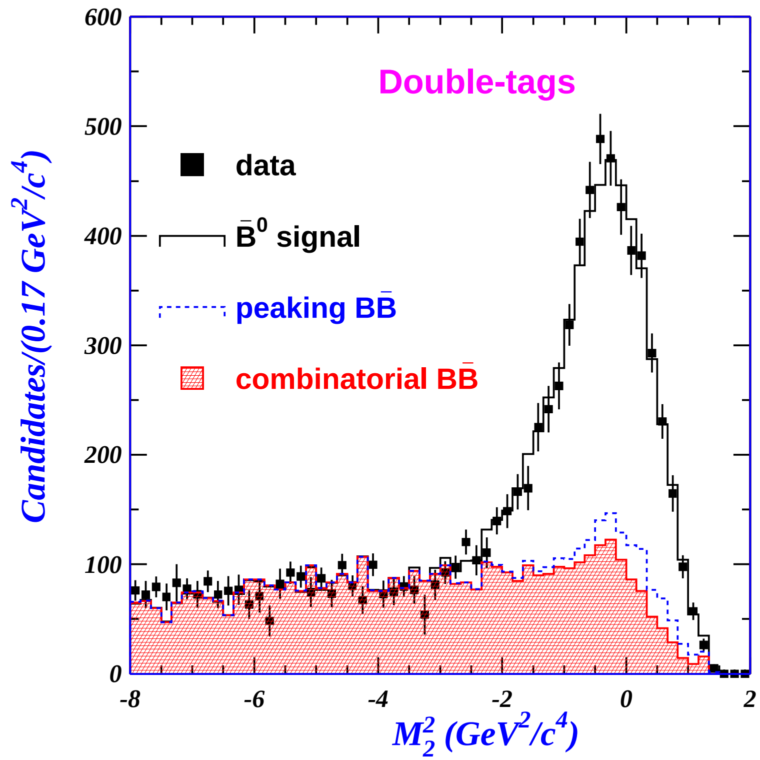
Fit Parameter	Signal region $\mathcal{M}_s^2$	Signal region $\mathcal{M}_2^2$	Whole region $\mathcal{M}_s^2$	Whole region $\mathcal{M}_2^2$
Different	-1300 ± 2100	-80 ± 80	-700 ± 3000	-70 ± 80
C.L.(%)	57	78	94	98

Data Fits

Single Tags



Double Tags



- Single tags χ^2 binned fit (continuum has been subtracted)

- Double tags χ^2 binned fit (continuum, $\mathcal{M}_1^2$ combinatoric, and $\mathcal{M}_1^2$ peaking have been subtracted)

Signal Yields

Summary of Fitting Results

Source	$\mathcal{M}_s^2$	$\mathcal{M}_2^2$
Combinatorial $B\overline{B}$	558080 ± 470	1510 ± 20
Peaking $B\overline{B}$	68170 ± 260	300 ± 20
Continuum	240600 ± 1400	160 ± 40
$\mathcal{M}_1^2$-combinatorial	—	180 ± 20
$\mathcal{M}_1^2$-peaking	—	60 ± 10
Signal yields	786200 ± 1900	3560 ± 70
Confidence Level	11%	82%

Input parameters :

- $N_s = (78.62 \pm 0.19) \times 10^4$
- $N_d = (35.6 \pm 0.7) \times 10^2$
- $N_{B\overline{B}} = (88.7 \pm 1) \times 10^6$
- $C = 0.995 \pm 0.008$

Systematic Errors

Summary of the absolute systematic error for f_{00}

Source	$\delta(f_{00})$
Total $B\overline{B}$ events	0.0055
Peaking background	0.0040
$\Upsilon(4S) \to$ non-$B\overline{B}$	0.0025
Same-charge samples	0.0025
MC statistics	0.0020
Efficiency correlation	0.0015
$\mathcal{M}_1^2$-combinatorial	0.0005
$\mathcal{M}_1^2$-peaking	0.0005
Total	0.008

- The dominant systematic error comes from total $B\overline{B}$ events including hadronic selection and tracking efficiency
- Systematic error due to lepton and pion momentum spectrums are negligible
- This result depends very weakly on the simulated reconstruction efficiency

Romulus Godang
University of Mississippi

Summary

- Direct measurement of $f_{00} \equiv \mathcal{B}(\Upsilon(4S) \to B^0\overline{B}^0)$ (preliminary)

$$f_{00} = 0.487 \pm 0.010_{stat} \pm 0.008_{syst}$$

- This result has been submitted to PRL (hep-ex/0504001)

- This clean measurement does not depend on
  - B and D branching fractions
  - B^+ and $\overline{B}^0$ lifetime
  - B isospin symmetry

- This precision measurement is important for
  - B branching fraction measurements
  - Isospin violation in the $\Upsilon(4S)$ decays
  - $\Upsilon(4S) \to$ non-$B\overline{B}$ fraction (poorly known)