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Proposal for Running at the $\Upsilon(5S)$ at PEP-II

The *BABAR* Collaboration

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Abstract

The observation of the $\Upsilon(5S)$ resonance is an important step to evaluate the feasibility of using measurements of $\overline{B_s}^0$ decays to test the theoretical models of $\overline{B_s}^0$ meson decays. We discuss a measurement of absolute branching fraction $\overline{B_s}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ at the $\Upsilon(5S)$ using a double-tag technique. We partially reconstructed the decays $\overline{B_s}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$, where we only use the information from the charged lepton combined with the soft photon from the decay $D_s^{*+} \to D_s^+\gamma$.

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Measurement Capabilities of the $\Upsilon(5S)$ at *BABAR*

1 Introduction

The total hadronic $\Upsilon(5S)$ cross section was first measured as a function of energy at CESR [1, 2, 3]. The $\Upsilon(5S)$ cross section was approximately 0.35 nb with an e^+e^- center-of-mass energy of 10.865 ± 0.008 GeV. The relative population of ground-state B mesons in the energy region of $10.73 - 10.93$ GeV is shown in Fig. 1.

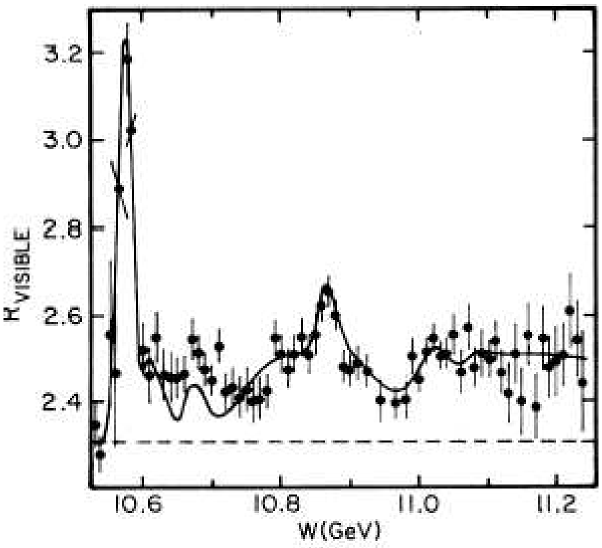

Figure 1: Model calculation superimposed on data. [PRL 54, 377 (1985)].

The Upsilon hadronic cross section is well described by the Unitarized Quark Model (UQM) [4], which is a coupled-channel model. This model calculation predicts the dominant hadronic decay modes from $\Upsilon(5S)$ system that occurs at an e^+e^- center-of-mass energy are primarily the combination of $B_s\overline{B_s}$, $B_s\overline{B_s^*}$, $B_s^*\overline{B_s}$, and $B_s^*\overline{B_s^*}$ which is about one third of the total $\Upsilon(5S)$ cross section. This is implied that the other channels: $B\overline{B}\pi$, $B\overline{B}\pi\pi$ and $B\overline{B^*}\pi$ are negligible. The relative rates of each channel with respect to the cross section of $B_s^*\overline{B_s^*}$ have been computed using several models [3, 4]:

$$\sigma(B_s\overline{B_s})/\sigma(B_s^*\overline{B_s^*}) \sim 0.1 - 0.2 \tag{1}$$

and

$$\sigma(B_s\overline{B_s^*} + B_s^*\overline{B_s})/\sigma(B_s^*\overline{B_s^*}) \sim 0.05 - 0.5 \tag{2}$$

The flavored mesons B_s^* and its combinations that produced at the $\Upsilon(5S)$ are directly decay to a B_s and a soft photon that give us a combination of $B_s\overline{B_s}$. The comparison between the branching fraction on data from CLEO with the UQM is shown in Fig. 2.

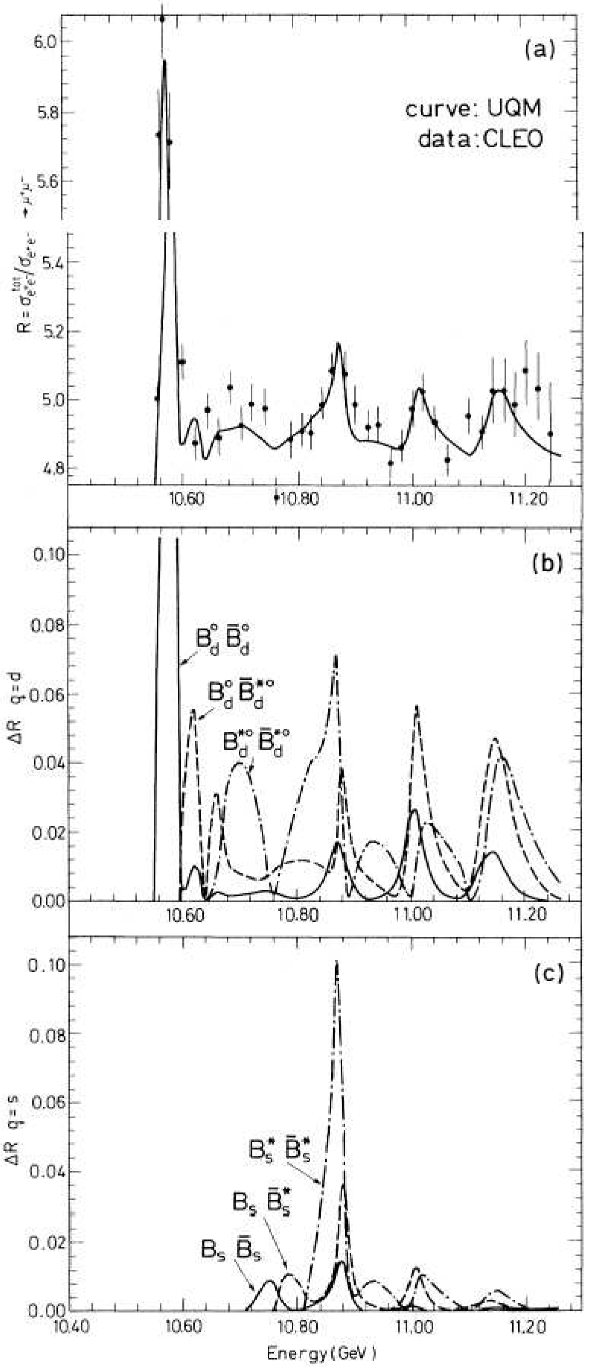

Figure 2: The comparison between data from CLEO with the UQM [PRL 55, 2938 (1985)]. (a) data on the branching fraction, R, from CLEO compared with the UQM. (b) the contribution to R from non-strange neutral channels in the UQM. (c) the contribution to R from strange B mesons.

In this document, we use the symbol $B_s^{(*)}\overline{B_s^{(*)}}$ to denote the sum of all fractions of $\Upsilon(5S)$ decay to any B meson type final states.

2 Absolute Branching Fraction of $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$

The $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$ decay is reconstructed partially by identified lepton $(\ell = e, \mu)$ in combination with a photon from the decay $D_s^{*+} \to D_s^+\gamma$, without explicit D_s^+ reconstruction. The presence of an undetected neutrino is inferred from conservation of momentum and energy. The number of signal events, $\mathcal{N}$, is extracted using a "missing mass squared" variable:

$$\mathcal{M}_m^2 = (E_B - E_{D_s^*} - E_\ell)^2 - (\mathbf{p}_B - \mathbf{p}_{D_s^*} - \mathbf{p}_\ell)^2, \tag{3}$$

where E_B is half the center-of-mass (CM) energy in the $\Upsilon(5S)$ system and $\mathbf{p}_B \sim 800$ MeV that produced parallel to the beam axis. The $\mathbf{p}_\ell$ $(\mathbf{p}_{D_s^*})$ are the center-of-mass energy and momentum of the lepton (D_s^* meson).

We use a novel double-tag technique that has been used in $\Upsilon(4S)$ system [5]. We partially reconstructed the decays $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$. The inclusion of charge-conjugate reactions is implied throughout this document. We labeled the "single-tag sample" for the sample of events in which at least one $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ candidate decay is found. The number of events for the single-tag sample is denoted as $\mathcal{N}_s$ and it can be extracted by

$$\mathcal{N}_s = 2N_{\Upsilon(5S)} f_{s(*)}\ \varepsilon_s\ \mathcal{B}(\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell)\mathcal{B}(D_s^{*+} \to D_s^+\gamma), \tag{4}$$

where $N_{\Upsilon(5S)}$ is the total number of $\Upsilon(5S)$ mesons produced in the data sample. The value of $f_{s(*)}$ is the sum of all fractions of the $\Upsilon(5S)$ that decays into $B_s^{(*)}\overline{B_s^{(*)}}$ combinations:

$$f_{s(*)} = \sum_i f_s^i, \tag{5}$$

where f_s^i is the fraction of each combination of $B_s\overline{B_s}$, $B_s\overline{B_s^*}$, $B_s^*\overline{B_s}$, and $B_s^*\overline{B_s^*}$ at the $\Upsilon(5S)$ system. The ε_s is the reconstruction efficiency for $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$.

The number of signal events in the subset in which two $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$ candidates are found is labeled the "double-tag sample". The number of such events in this sample is denoted as $\mathcal{N}_d$ and it can be extracted by

$$\mathcal{N}_d = N_{\Upsilon(5S)} f_{s(*)}\ \varepsilon_d\ [\mathcal{B}(\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell)\mathcal{B}(D_s^{*+} \to D_s^+\gamma)]^2, \tag{6}$$

where ε_d is the efficiency to reconstruct two $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$ decays in the same event. From Eq. (4) and Eq. (6), the product branching fraction of $\mathcal{B}(D_s^{*+}\ell^-\bar{\nu}_\ell)\mathcal{B}(D_s^{*+} \to D_s^+\gamma)$ can be written as

$$\mathcal{B}(\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell) \times \mathcal{B}(D_s^{*+} \to D_s^+\gamma) = \frac{2\mathcal{N}_d\varepsilon_s}{\mathcal{N}_s\varepsilon_d} \tag{7}$$

Using $\mathcal{B}(D_s^{*+} \to D_s^+\gamma) = (94.2 \pm 2.5)\%$ [7], the absolute branching fraction of $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ can be extracted by

$$\mathcal{B}(\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell) = \frac{2\mathcal{N}_d\varepsilon_s}{\mathcal{B}(D_s^{*+} \to D_s^+\gamma)\mathcal{N}_s\varepsilon_d}, \tag{8}$$

where the factors $N_{\Upsilon(5S)}$ and $f_{s(*)}$ are drop out, therefore, this absolute branching fraction value of $\overline{B}_s^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ is a model independent measurement. The reconstruction efficiencies of the single-tag and the double-tag samples have many features in common and therefore many shared systematic uncertainties which cancel at least partially in taking the ratio.

Based on our measurement of the branching fraction of $\Upsilon(4S) \to B^0\overline{B}^0$ in $\Upsilon(4S)$ system [5], we estimate the reconstruction efficiency for $\overline{B}_s{}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ ($D_s^{*+} \to D_s^+\gamma$) both for the single-tag and the double-tag samples. Using CLEO model dependent measurement of $\Upsilon(5S) \to B_s^{(*)}\overline{B_s^{(*)}} \equiv f_{s(*)} = (21 \pm 3 \pm 9)\%$ [8], $\mathcal{B}(D_s^{*+} \to D_s^+\gamma) = (94.2 \pm 2.5)\%$, and assuming we have data samples of $100\,\mathrm{fb}^{-1}$ collected at the $\Upsilon(5S)$ resonance with the *BABAR* detector at the PEP-II asymmetric-energy e^+e^- storage ring, we calculate the number of events for the single-tag and the double-tag samples to be 103635 ± 322 and 365 ± 19, respectively. The efficiencies of ε_s and ε_d are estimated about 50% of those efficiencies based on the Monte Carlo calculation in $\Upsilon(4S)$ system [5]. Random photons from π^0 decays could add background and reduce the sensitivity [6]. We assume the same efficiencies for both the B_s and B_s^* decay chains since both chains are quite good agreement in their $\mathcal{M}_m^2$ distribution with a resolution of 1.61 GeV^2/c^4 for B_s^* and 1.68 GeV^2/c^4 for B_s as shown in Fig. 3. The dominant statistical error is expected coming from the the number of events in the double-tag sample, therefore we could achieve a measurement of the absolute branching fraction of $\overline{B}_s{}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ with a precision of $\sim 5\%$.

3 Toy Monte Carlo Study

We generated $\Upsilon(5S)$ events in a toy Monte Carlo. The electron/positron beam energies were scaled to 9.24 and 3.19 GeV respectively to produce a center of mass energy $E_{CM} = 10.865$ GeV. The four combinations of $\Upsilon(5S) \to B_s(5370)^{(*)}\overline{B}(5370)_s^{(*)}$ were produced using equal rates with $B_s^* \to B_s\gamma$. Then we forced $B_s(5370) \to D_s^*(2112)\ell^+\nu_\ell$ and $D_s^*(2112) \to D_s(2010)\gamma$. Similarly for the $\overline{B}(5370)_s^*$ decay chain. The final state particles of interest in the analysis, γ and ℓ were subject to a cosine θ_{CM} constraint of $-0.866 < cos(\theta_{CM}) < +0.866$. The γ, ℓ energy-momentum vectors were smeared with a pseudo-*BABAR* type resolution function which produces a reasonable match to *BABAR* data. We apply a CM lepton momentum cut of 1.5 GeV/c $\leq P_\ell^* \leq$ 2.5 GeV/c and γ CM energy cut 60 MeV $\leq E_\gamma^* \leq$ 400 MeV. Note that because the $D_s^{*+} \to D_s^+\gamma$ decay is less constrained by phase space, backrounds may be more of an issue at the $\Upsilon(5S)$. This is under investigation.

The $\mathcal{M}_m^2$ distribution of $\overline{B}_s{}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ ($D_s^{*+} \to D_s^+\gamma$) is shown in Fig. 4. The $\mathcal{M}_m^2$ distribution has a resolution of 1.68 GeV^2/c^4 with ranging from -8 to 2.5 GeV^2/c^4 . Figure 5 shows the lepton and photon momentum distribution of $\overline{B}_s{}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ ($D_s^{*+} \to D_s^+\gamma$) for the single-tag Monte Carlo sample. The lepton momentum has a resolution of 0.5 GeV/c and the photon momentum has a resolution of 77 MeV/c.

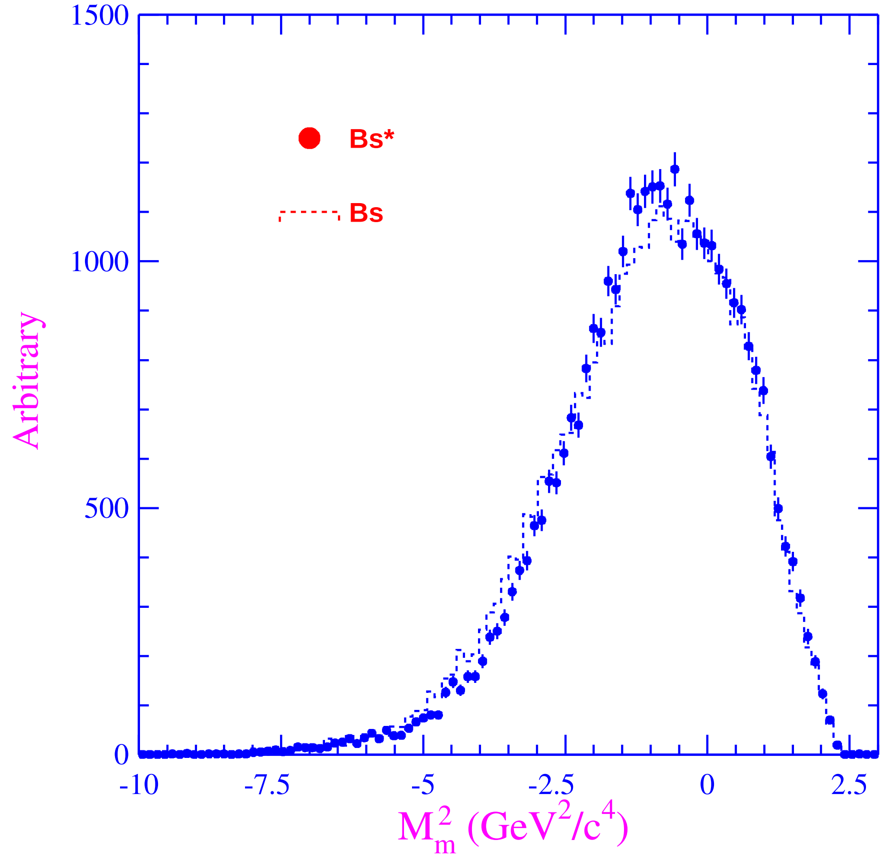

Figure 3: Missing mass squared distribution of $\overline{B_s}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ $(D_s^{*+} \to D_s^+\gamma)$ (dash) and B_s^* decay chain (filled solid) for the single-tag Monte Carlo sample.

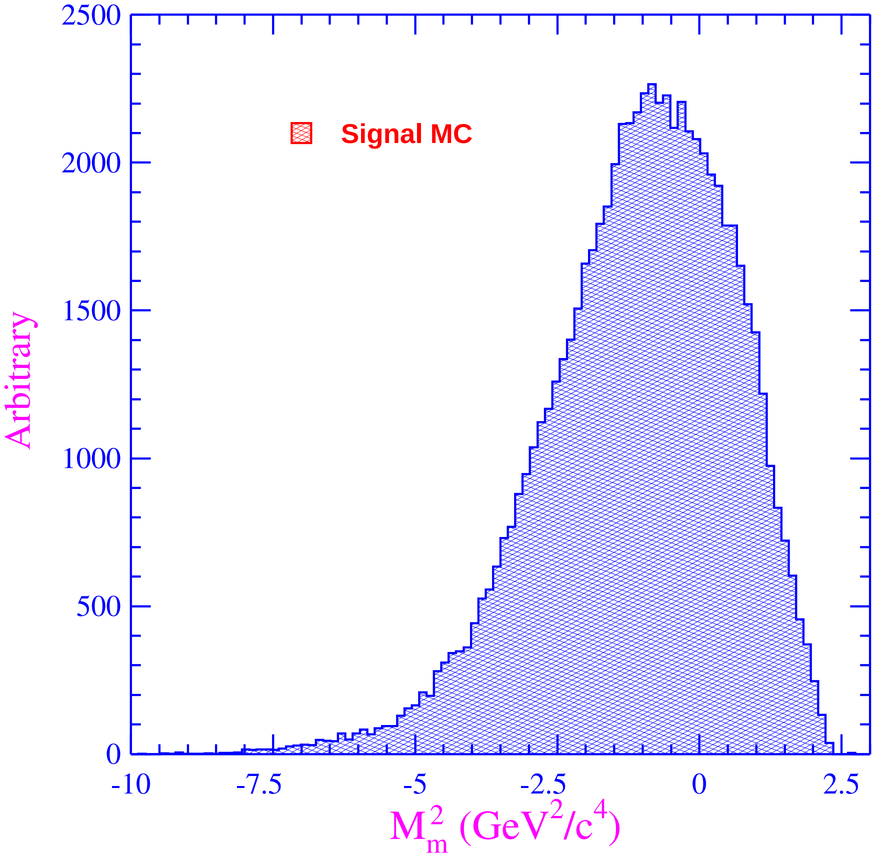

Figure 4: Missing mass squared distribution of $\overline{B_s}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ ($D_s^{*+} \to D_s^+\gamma$) for the single-tag Monte Carlo sample.

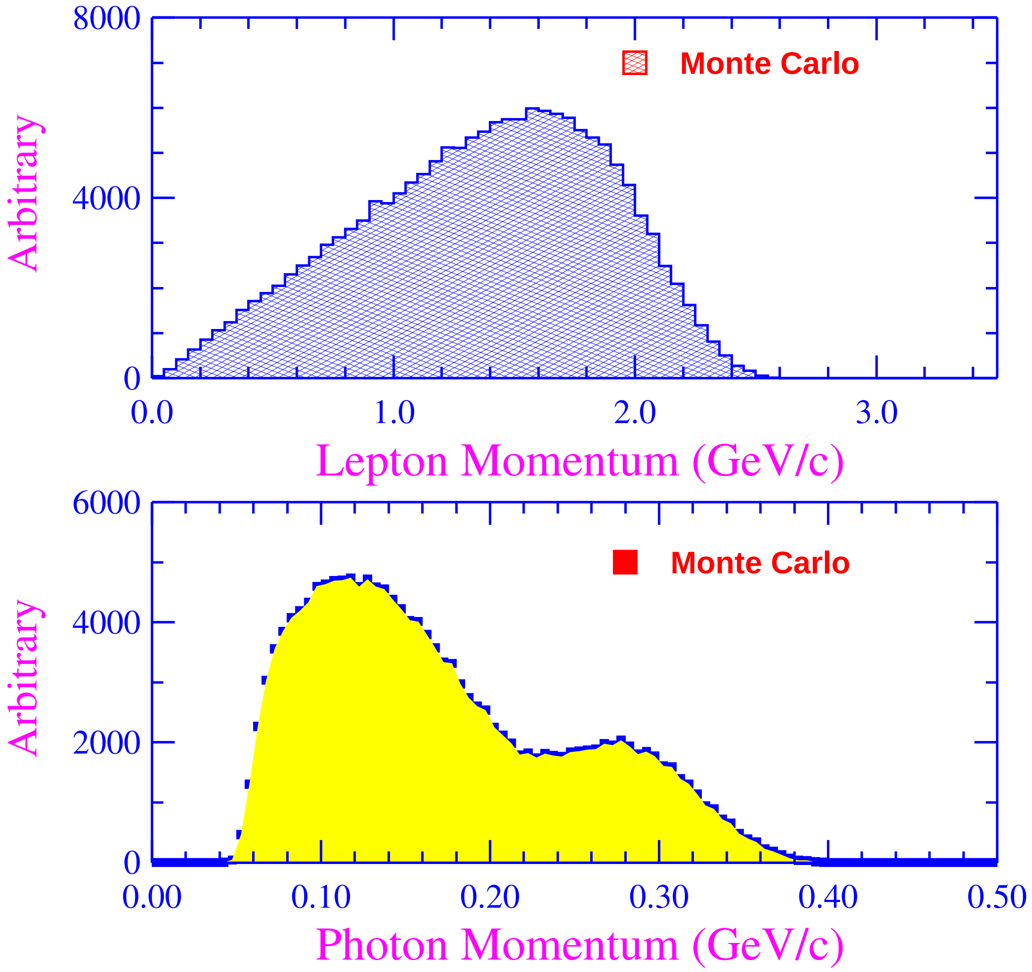

Figure 5: Lepton momentum (upper) and photon momentum (lower) distributions of $\overline{B_s}^0 \to D_s^{*+}\ell^-\bar{\nu}_\ell$ ($D_s^{*+} \to D_s^+\gamma$) for the single-tag Monte Carlo sample.

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