First measurement of the B_S meson mass

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The ALEPH Collaboration

Abstract

In a sample of about 1.1 million hadronic Z decays recorded with the ALEPH detector during the 1990-1992 running of LEP, two unambiguous B_S meson candidates were observed. From these events the mass of the B_S meson has been measured to be $5.3686 \pm 0.0056(stat.) \pm 0.0015(syst.)$ GeV.

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Introduction

In the recent past, some progress has been made in the experimental study of the production and decay of the B_S meson [1, 2, 3, 4, 5]. Furthermore, a possible candidate for $B_S \rightarrow J/\psi\phi$ has previously been reported [5]. While the semileptonic decay of B_S meson has been observed and the B_S lifetime has been measured [6], the mass of the B_S meson is not well-known experimentally. Apart from providing an important test of the quark model prediction [7, 8], a precise measurement of the B_S mass is important for subsequent studies of B_S decays.

In this letter the first measurement of the B_S meson mass via complete reconstruction of its decay final states is reported. This measurement is based on a sample of 1.1 million hadronic Z decays recorded with the ALEPH detector during the 1990-1992 running of LEP. Preliminary version of this analysis was reported in [9].

The ALEPH Detector

The ALEPH detector has been described in detail elsewhere [10]. Charged tracks are measured over the range $|\cos\theta| < 0.966$, where θ is the polar angle, by an inner cylindrical drift chamber (ITC) and a large cylindrical time projection chamber (TPC). These chambers are immersed in a magnetic field of 1.5 T and together measure the momentum of charged particles with a resolution of $\delta p/p = 0.0008p\,(GeV)^{-1} \oplus 0.003$ [10, 11]. Since 1991, tracks in the central polar region are also measured by a vertex detector (VDET) [12] which consists of two concentric barrels of microstrip silicon detectors, with double-sided readout, positioned between the beam pipe and the ITC at radii of 6.4 and 11.5 cm. The detectors are arranged in such a way as to provide full azimuthal coverage. The coverage in the polar angle is $|cos\theta| < 0.85$ for the inner layer and $|cos\theta| < 0.65$ for the outer layer. The momentum resolution for high momentum charged particles with VDET coordinates improves to $\delta p/p = 0.0006p\,(GeV)^{-1}$. The VDET point resolution, as measured with data [13] is 12 μm at normal incidence for both $r\phi$ and rz projections.

The TPC provides up to 330 measurements of the specific ionization (dE/dx) of each charged track,with a measured dE/dx resolution of 4.6% for 330 ionization samples. For charged particles with momenta above 3 GeV, the (60% truncated) mean specific ionization of pions and kaons is typically separated by two standard deviations.

The fine grained electromagnetic calorimeter (ECAL), which surrounds the TPC and is inside the coil of the superconducting solenoid, is used to measure electromagnetic energy and, together with the TPC, to identify electrons. The hadron calorimeter (HCAL) is composed of the iron of the magnet return yoke interleaved with 23 layers of streamer tubes. The HCAL is surrounded by the muon chambers, two additional double layers of streamer tubes that cover the same angular range. The muon chambers are read out by cathode strips both parallel and perpendicular to the tubes. Therefore each layer provides a three-dimensional coordinate for charged tracks which penetrate the 7.5 interaction lengths of material between the production point and the muon chambers.

The selection of hadronic events is based on charged tracks and has been described elsewhere [14]. In the remainder of this section, two algorithms which are of significance for this analysis are briefly discussed.

The interaction point is reconstructed on an event-by-event basis with a method [15] which takes advantage of the precise 3D coordinates for charged tracks provided by the VDET. Charged tracks in a hadronic event are grouped into jets and projected onto a plane perpendicular to the associated jet direction. The interaction point is then calculated as the point which is most consistent with the intersection point of the projected tracks and the nominal luminous region found from averaging every group of 75 Z decays [16]. With this algorithm, the measured resolution on the interaction point [1] is 50 μm along the x and z axes. In the y direction the beam is narrower than 10 μm. Using this event-by-event reconstructed interaction point, the resolution (σ_δ) on the three dimensional signed impact parameter (δ) for tracks with at least one three dimensional VDET hit and momenta above 3 GeV is about 50 μm.

This ability to precisely measure the impact parameter of a charged track has been used to construct an algorithm [17] which distinguishes $Z \to b\overline{b}$ from $Z \to u\overline{u}, d\overline{d}, s\overline{s}$ events. Due to the large mass of the b hadrons and their relatively long lifetime, $Z \to b\overline{b}$ events at LEP energies are characterised by the presence of many charged tracks with significant signed impact parameter (δ/σ_δ) with respect to the interaction point. In contrast, most tracks in $Z \to u\overline{u}, d\overline{d}, s\overline{s}$ events emerge from the interaction point, consequently the δ/σ_δ for these tracks are small. In $Z \to c\overline{c}$ events an intermediate situation exists. While charm hadrons have a typical decay length of about 1.5mm, the multiplicity in charm hadron decays is small. Consequently only a few charged tracks in $Z \to c\overline{c}$ events have large δ/σ_δ. In order to distinguish $Z \to b\overline{b}$ events from other hadronic Z decays, a probability function (P_{uds}) was constructed based on the δ/σ_δ of each track in the event. For events within the VDET acceptance, the requirement that the event have P_{uds} less than 0.1 eliminates 85% of the $Z \to u\overline{u}, d\overline{d}, s\overline{s}$ events, 71% of $Z \to c\overline{c}$ events and only 18% of $Z \to b\overline{b}$ events.

B_S Reconstruction

B_S meson mass reconstruction was performed in events with charged tracks satisfying the kinematic constraints for the following low multiplicity B_S meson decay modes:

$$B_S \to D_S^- \pi^+ \quad (1)$$
$$B_S \to D_S^- a_1^+ \quad (2)$$
$$B_S \to J/\psi \phi \quad (3)$$
$$B_S \to \psi' \phi \quad (4)$$
$$B_S \to K^- \overline{D^0} \pi^+. \quad (5)$$

Here and throughout this paper charge conjugate reactions are also implied.

The charm mesons and other resonant states were reconstructed in decay modes listed in Table 1. The observed masses and mass resolutions are also listed. In addition, J/ψ and ψ' candidates were reconstructed by their decay into e^+e^-. A cut on the e^+e^- invariant mass of 0.1 GeV around the nominal J/ψ and ψ' mass was imposed.

[1]The z direction is along the beam and the y direction is vertical.

Decay Channel	Observed Mass (Stat. Error only)	Observed Mass Resolution (rms)	PDG Mass [18]
$K^{*0} \rightarrow K^+\pi^-$	0.895 ± 0.001	–	0.8961 ± 0.0003
$\phi \rightarrow K^+K^-$	1.0196 ± 0.0005	0.003	1.0194 ± 0.0004
$D^0 \rightarrow K^-\pi^+$	1.8647 ± 0.0003	0.0105	1.8645 ± 0.0005
$D_S^+ \rightarrow \phi\pi^+$	1.9686 ± 0.0007	0.0076	1.9688 ± 0.0007
$D_S^+ \rightarrow \overline{K^{*0}}K^+$	1.968 ± 0.001	0.008	1.9688 ± 0.0007
$D_S^+ \rightarrow \overline{K^0}K^+$	1.967 ± 0.004	0.013	1.9688 ± 0.0007
$J/\psi \rightarrow \mu^+\mu^-$	3.0964 ± 0.0023	0.023	3.09693 ± 0.00009
$\psi' \rightarrow \mu^+\mu^-$	3.679 ± 0.014	0.028	3.6860 ± 0.0001

Table 1: The decay modes used for B_S reconstruction. The observed masses, resolutions and the nominal Particle Data Group masses are quoted in GeV. The natural width of the K^{*0} resonance is about four times larger than the detector resolution.

The B_S meson candidate mass was computed by a kinematic constrained fit [19] in which the mass of the charm hadron ($D_S^+, D^0, J/\psi, \psi'$) was constrained to the known values [18]. The improvement in the mass resolution from such a constrained fit was largely in the $B_S \rightarrow \psi\phi$ and $B_S \rightarrow \psi'\phi$ channels because the J/ψ or ψ' carry a large fraction of the B_S momentum. Monte Carlo simulations predict an average B_S mass resolution, after the constrained fit, of 8.5 MeV for the $B_S \rightarrow \psi'\phi$ decay mode and 25 MeV for the $B_S \rightarrow D_S^-\pi^+$ mode.

The main difficulty in reconstructing B_S decays is the very large number of random track combinations which have an apparent mass between 4 and 6 GeV. They can be classified in three categories:

(1) Spurious combinations of tracks in $Z \rightarrow u\overline{u}, d\overline{d}, s\overline{s}$ *and* $c\overline{c}$ events.

(2) Track combinations in $Z \rightarrow b\overline{b}$ events made with spurious charm meson candidates.

(3) Spurious track combinations in $Z \rightarrow b\overline{b}$ events made with true charm hadrons. To reduce these combinatorial backgrounds stringent selection criteria were used for B_S mass reconstruction. Background (1) was largely eliminated by requiring that the event have a probability P_{uds} for being a $Z \rightarrow u\overline{u}, d\overline{d}, s\overline{s}$ event of less than 0.1.

For B_S meson reconstruction, only charged tracks with momenta greater than 1 GeV were considered. Particles assigned as kaons were required to have momenta greater than 2 GeV and the specific ionization of the track in the TPC was required to be consistent with the kaon hypothesis (2σ). An exception to this requirement was made in case of kaons from ϕ decay. The reconstructed charm meson candidate mass was required to be within fixed cuts approximately at two standard deviations of the known value. The ϕ, K^{*0} and a_1^+ candidates were required to have reconstructed masses within 6, 50 and 300 MeV, respectively, of the known value.

The topology of the B_S meson decay in conjunction with the precise tracking capability of the ALEPH detector, permits a strict suppression of the combinatorial backgrounds of all three afore-mentioned classes. For example, in the decay $B_S \rightarrow D_S^- a_1^+$, the B_S

meson decay vertex is displaced on average by about 2.5 mm with respect to the interaction point. The $a_1^+ \to \pi^+\pi^-\pi^+$ decays promptly at the B_S decay point while the D_S^- decays further downstream. The typical 3D vertex reconstruction error, in the B_S flight direction is about 250 μm for the B_S vertex and about 350 μm for charm hadron vertex. The interaction point is known, on average, to 70 μm in the B_S flight direction. Hence these vertices can be resolved from the interaction point. The charged tracks forming combinatorial background, in contrast, either come from the interaction point or are not spatially correlated (as in the case of (3)).

To take advantage of this distinction between signal and background the following requirements were made:

(a) The daughter tracks of the B_S were required to form a consistent three dimensional vertex. A similar requirement was also made on the charm hadron decay daughters.

(b) The B_S and charm hadron vertices were required to be downstream from the interaction point.

(c) The B_S meson vertex was required to be displaced with respect to the interaction point by at least 500 μm.

These requirements lead to a large (approximately a factor of 8) rejection of combinatorial background for most B_S decay modes considered in this analysis.

In addition to the combinatorial background, there is another form of background which populates the B_S candidate mass spectrum in several of the channels analyzed. This background arises when the π or kaon tracks are sufficiently energetic that any kinematic distinction between them is lost. For example, in the decay $D^- \to K^{*0}\pi^-$ or $D^- \to K^0\pi^-$, when the pion is very energetic, misinterpretation of the π^- as a K^- will form a K^{*0}"K^-" or K^0"K^-" mass close to the known D_S^- mass [2]. As a consequence, the daughters in the decay $B_d^0 \to D^-\pi^+, D^- \to K^{*0}\pi^-$ *or* $K^0\ \pi^-$, form "D_S^-" π^+ invariant mass near 5.36 GeV with an rms spread of 50 MeV when the π^- from the D^- decay is misinterpreted as a kaon. Similarly, the decay mode $B_S \to K^-\ \overline{D^0}\ \pi^+$ faces contamination from the analogous channels $B_d^0 \to \pi^-\overline{D^0}\pi^+$ and $\Lambda_b \to pD^0\pi^-$. Monte Carlo simulations show that the reflected mass from B_d^0 peaks near 5.36 GeV with an rms spread of 45 MeV. The reflected mass from Λ_b peaks near 5.4 GeV (assuming $M_{\Lambda_b} = 5.6$ GeV) and has an rms spread of about 125 MeV. These reflection background considerations do not apply to all B_S decay modes considered in this analysis. Three decay modes can be considered unambiguous due to the narrow width of the ϕ resonance. They are :

$$B_S \to J/\psi\phi \quad (6)$$

$$B_S \to \psi'\phi \quad (7)$$

$$B_S \to D_S^-\pi^+, D_S^- \to \phi\pi^- \quad (8)$$

The contamination from reflections in other decay modes was suppressed by requiring that the kaon candidate in $D_S^- \to \overline{K^{*0}}K^-, \overline{K^0}K^-$ and $B_S \to K^-\overline{D^0}\pi^+$ decay modes have specific ionization in the TPC consistent (within 2σ) with the kaon hypothesis. This requirement eliminates half of the reflection background from B_d^0 decays. The residual background from B_d^0 was estimated to be 1.5 ± 0.6 from the known B_d^0 branching ratios

[2]This reflection is symmetric, $D_S^- \to K^{*0}K^-$ also reflects near the D^- mass with similar frequency.

and Monte Carlo simulation [20] of these decay processes. The error on the estimate reflects the poor knowledge of B branching ratios. The background contribution from $\Lambda_b \to pD^0\pi^-$ was estimated to be 0.3 ± 0.3 assuming that $\mathrm{Br}(\Lambda_b \to pD^0\pi^-) = 0.2 \pm 0.2\%$. Hence the total background of 1.8 ± 0.7 events was estimated.

In about one million hadronic Z decays, 11 events satisfying the afore-mentioned criteria were observed with a mass above the known $B^{0,+}$ masses [18]. These candidates were scanned to search for any attributes which would be clearly inconsistent with the B_S hypothesis like pattern recognition problems in tracking, signs of nuclear interaction and particle identification problems. In this manner, two B_S candidates near 5.36 GeV were rejected. The remaining nine events have a mass between 5.3 and 5.42 GeV. No events were found with a mass between 5.42 and 6.0 GeV. Among these events, seven were observed in decay modes which suffer from reflection background. Four candidates were observed in the $B_S \to K^-\overline{D^0}\pi^+$ mode, two in $B_S \to D_S^-\pi^+, D_S^- \to \overline{K^{*0}}K^-$ mode and one candidate was observed in $B_S \to D_S^- a_1^+, D_S^- \to \overline{K^0}K^-$ decay mode. In this sample the combinatorial background was expected to be one event. Due to the symmetric nature of the kinematic reflection and also due to the large error on the measured Λ_b mass, all but one B_S candidate in this sample are consistent with the B^0 or Λ_b mass hypothesis. Consequently, these events were not used for the B_S mass measurement.

Measurement of the B_S Mass

No B_S candidate events were found in a mass range between 4.5 and 6.0 GeV in the $B_S \to J/\psi\phi$ decay mode. In the same mass range one event was observed in the $B_S \to \psi'\phi$ mode. The measured B_S mass is 5.3684 ± 0.0043 GeV. This event is displayed in fig. 1. There are two energetic tracks with momenta of 13.5 and 16.2 GeV which penetrate seven interaction lengths of iron and are well-identified as muons in the HCAL and the muon chambers. The $\mu^+\mu^-$ invariant mass is 3.692 ± 0.020 GeV, in good agreement with the known ψ' mass of 3.686 GeV. The ϕ candidate is composed of two tracks with momenta 7.2 and 5.1 GeV. Each of them has specific ionization in the TPC in good agreement with the kaon hypothesis. The K^+K^- invariant mass is 1.0204 ± 0.0008 GeV. Each of the four tracks has at least one three-dimensional coordinate in the VDET and most track coordinate assignments in the ITC and the TPC are unambiguous. These four charged tracks form a common vertex in three dimensions with a vertex χ^2 probability of 43%. The B_S decay vertex is displaced with respect to the interaction point by 4.53 ± 0.14 mm. The B_S momentum is 41.7 GeV, close to the beam energy of 45.6 GeV. In the process of hadronization of the b quark into a $\overline{B}_S$ meson it is expected that the remaining most energetic track be a charged or neutral kaon. In this event, aside from the four tracks forming the B_S, the most energetic particle in the hemisphere containing the B_S is a K_S^0 with measured mass of 0.486 ± 0.008 GeV, momentum of 1.63 GeV and decay length of 7.39 ± 0.48 cm with respect to the interaction point.

Several characteristics of this event can be used to dismiss any other plausible hypothesis. The large three dimensional impact parameter of these tracks imply that they come from a b hadron decay. The event is well-contained in the detector and the lack of missing energy in the hemisphere containing the B_S candidate excludes the possibility that the two muons making the ψ' candidate were instead produced in the double semileptonic decay of a b hadron ($b \to c\mu^-\nu, c \to X\mu^+\nu$). The B^0 hypothesis can be ruled out for this event by comparing the reconstructed mass with the precisely measured [18] B^0 mass. The B_S candidate tracks, when interpreted as $B^0 \to \psi' K^+\pi^-$ have a mass inconsistent to more than 10 standard deviations. The $\overline{B}^0 \to \psi' K^-\pi^+$ hypothesis was rejected on the basis of the observed mass at the five standard deviations level and also by the dE/dx information. These observations on this event are substantiated by studies performed with a large sample of simulated $Z \to \psi' X$ events. From these studies the expected combinatorial background above 5.0 GeV was estimated to be less than 0.006 events at 95% confidence level. The expected background from reflections from B^0 and Λ_b decays was estimated to be less than 0.0003 and 0.00008 events respectively.

The error on the measured B_S candidate mass could be underevaluated due to underestimations of the track parameter errors. From a study of the mass error using a sample of cleanly reconstructed D^{*+} and $J/\psi \to \mu^+\mu^-$ candidates and a measurement of the momentum error on muons in $Z \to \mu^+\mu^-$ events, a scale factor on the error on the mass of 1.3 ± 0.1 was estimated. After correcting for this error underestimation, the B_S candidate mass error was increased to ± 0.0056 GeV.

Another unambiguous B_S candidate was observed in the $\overline{B}_S \to D_S^+\pi^-, D_S^+ \to \phi\pi^+$ decay mode. The event is displayed in Fig. 2. Two oppositely charged tracks of momenta 3.2 and 4.0 GeV, identified in the TPC as kaons, form a ϕ candidate with mass $M_\phi = 1.020 \pm 0.001$ GeV. Together with a pion of momentum 2.26 GeV, they form a $D_S^+ \to \phi\pi^+$ candidate with an invariant mass of 1.959 ± 0.006 GeV and momentum of 9.3 GeV. Each of these three tracks has three dimensional coordinates in the VDET. They form a common vertex (vertex χ^2 probability is 38%) which is displaced by 2.71 ± 0.30 mm from the interaction point. Together with a π^- of momentum 31.6 GeV the D_S^+ candidate forms the B_S decay vertex (vertex χ^2 probability is 82%) at a distance of 1.57 ± 0.41 mm from the interaction point. The B_S momentum is 40.9 GeV. The measured B_S meson mass is 5.401 ± 0.077 GeV. This mass is in good agreement with the mass measured from the $B_S \to \psi'\phi$ candidate but has much larger error due to the large momentum of the π^- candidate. Given the large error on the reconstructed mass, the $B_S \to D_S^{*+}\pi^-$ hypothesis cannot be ruled out. The fine granularity of the ECAL permits a search for a low energy photon consistent with D_S^{*+}, but no such photon with momentum greater than 0.50 GeV was found. For this B_S candidate the possible background could be from $\overline{B}^0 \to D^+\pi^-$ and $\Lambda_b \to \Lambda_c^+\pi^-$ decays followed by $D^+ \to K^-\pi^+\pi^+$ and $\Lambda_c^+ \to K^-p\pi^+$ respectively. These hypotheses were rejected for this event because the $K^-\pi^+\pi^+$ and $K^-p\pi^+$ invariant masses were more than 10 standard deviations away from the nominal D^+ and Λ_c^+ mass, respectively. From Monte Carlo simulations of $Z \to b\bar{b} \to D_S^+ X$ events, the expected combinatorial background in a mass window of ± 0.150 GeV around 5.368 GeV was estimated to be less than 0.06 events at 95% confidence level. No other background hypothesis is plausible for this event.

There is another striking feature in this event. In addition to the tracks constituting the B_S candidate, there are two other tracks in the same hemisphere which come from the interaction point and have momenta of 3.6 and 1.2 GeV. The specific ionization of the fragmentation track with momentum of 3.6 GeV (labeled K_f) is in good agreement (0.3σ) with the kaon hypothesis. The pion hypothesis is disfavoured by 3.0 σ. This is additional

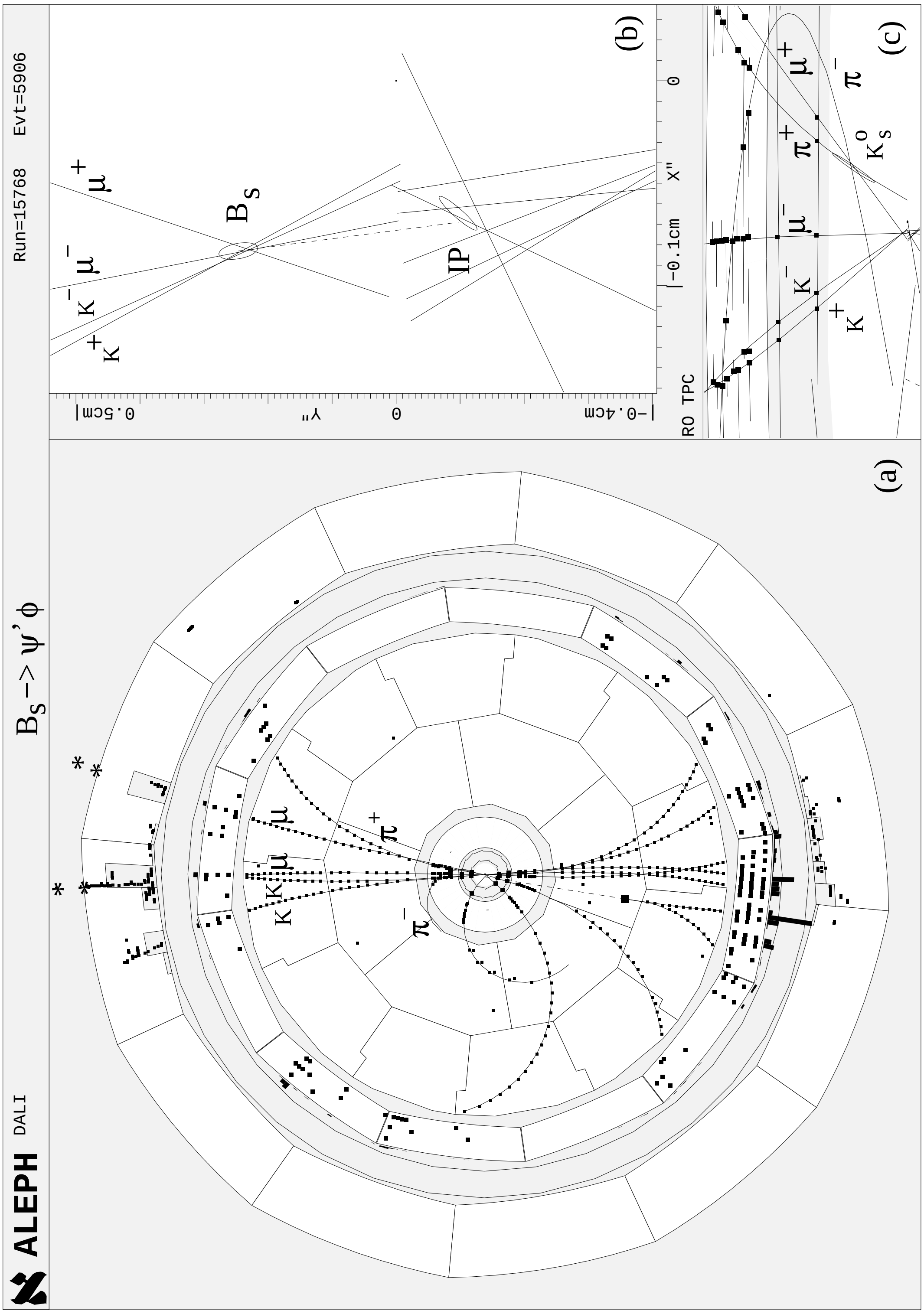

Figure 1: (a) A fisheye $r\phi$ view of the $B_S \rightarrow \psi'\phi$ event. The tracks forming the B_S meson are appropriately labeled. (b) A closeup view of the event near the interaction point. The error ellipses on the interaction point (IP) and the B_S vertex are 3σ. (c) A fisheye view of the event near the inner tracking chambers in the $r-\phi$ dimensions. The track coordinates recorded in the VDET and the ITC are shown. All tracks forming the B_S traverse a single silicon wafer in the inner and outer layer of the VDET minimizing mass measurement errors from possible internal misalignment in the VDET. The K^o_S decay daughters are labeled as π^+ and π^-. The vertex error ellipse is 3σ. The π^- track has momentum of 0.27 GeV and curls inside the ITC in the magnetic field of 1.5 T and has no coordinates in the TPC.

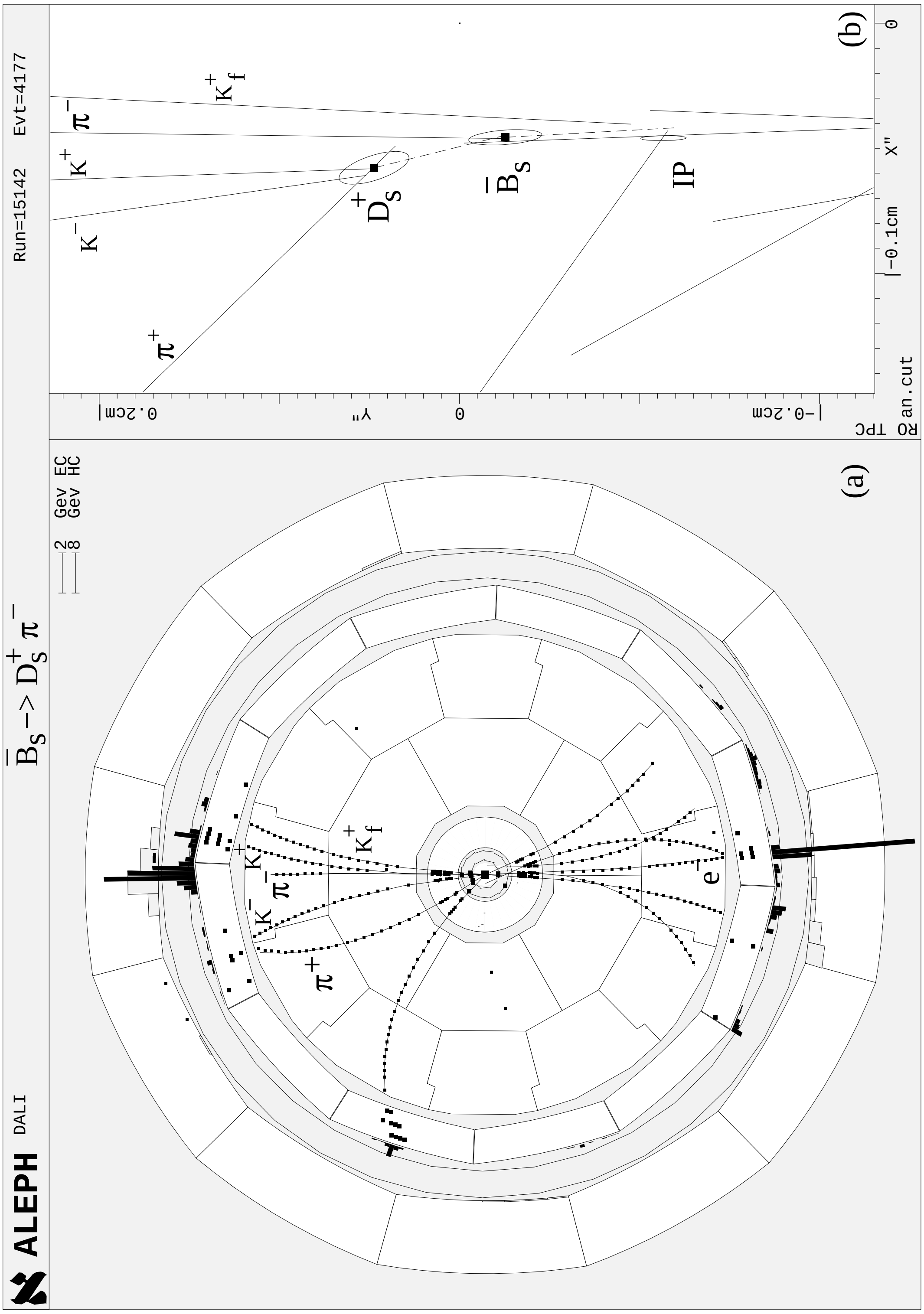

Figure 2: (a) A fisheye view of the $\overline{B}_S \to D_S^+\pi^-$ event in the $r\phi$ plane. The tracks forming the $\overline{B}_S$ meson are appropriately labeled. The kaon from fragmentation process and the opposite hemisphere electron which indicate that B_S meson has mixed are indicated as K_f and e^- respectively. (b) A closeup view of the event near the interaction point. The D_S^+ and $\overline{B}_S$ meson decay points are indicated. The error ellipses are 1σ.

Error Source	Magnitude	Systematic error on B_S Mass
Mass scale uncertainty	0.12%	0.0011
Remove worst hit in ITC + TPC	–	0.0004
Interchange ambiguous hits in ITC	–	0.0001
Tracking chamber misalignment	7 μm	0.0008
Track sagitta offset	0.3%	0.0003
Total		0.0015

Table 2: The principal sources of systematic error in the B_S mass measurement. The mass errors are quoted in GeV.

evidence for associated kaon production in the hadronization of the b quark into a B_S meson. Further, the electric charge of this kaon is positive implying that a B_S meson was produced at the interaction point, while the observed decay is $\overline{B}_S \to D_S^+\pi^-$. These features of the event are consistent if a B_S meson ($\overline{b}s$) was produced at the interaction point, underwent $B_S - \overline{B}_S$ oscillation and decayed as a $\overline{B}_S$ meson ($b\overline{s}$). This hypothesis is strengthened by the presence of a prompt electron (e^-), in the opposite hemisphere, with momentum of 10.6 GeV and transverse momentum (with respect to the associated jet) of 1.28 GeV. Taking into account the presence of background and the possibility of mixing, this electron tags the production of a b quark in the hemisphere with a probability of 85%.

From a weighted average of the two unambiguous events, the B_S mass was

$$M_{Bs} \;=\; 5.3686 \;\pm\; 0.0056 \; GeV.$$

Systematic Error on B_S Mass Measurement

The B_S mass measurement is dominated by the $B_S \to \psi'\phi$ event. The systematic error on the mass measurement was estimated by studying the specific features of the this event, the tracking performance measured from $Z \to \mu^+\mu^-$ events and the general capability of the ALEPH detector in measuring the masses of the charm hadrons. The most significant contributions to the systematic error are listed in table 2 and shall be discussed below. Processes such as decay in flight of kaons, multiple scattering, nuclear interaction in the tracking volume and misassignment of track coordinates (especially for the kaon tracks in the ϕ decay) can lead to a gross mismeasurement of the B_S mass. This possibility was checked by generating 700 events with the topology of the observed event and simulating the response of the ALEPH tracking system. The resulting $\mu^+\mu^-K^+K^-$ invariant mass distribution was fitted with a Gaussian. The observed mass was 5.3683 ± 0.0008 GeV with an r.m.s of 0.0050 ± 0.0001 GeV. No non-Gaussian tails were observed. Possible biases in the ψ' mass-constrained fit were checked by generating 1000 fully simulated $B_S \to \psi'\phi$ events. The reconstructed mass was found to be in good agreement with the generated value.

From a comparison of the reconstructed mass of the D^0, D^+ and ψ hadrons with their known values [18], the mass scale of the ALEPH detector is known to better than 0.12%. Due to the ψ' mass constraint imposed in the fit, the effect of a 0.12% scale error on the B_S mass measurement is 0.0011 GeV. The effects of possible misassignment of the track hit coordinates in the VDET, the ITC and the TPC were studied. It was not possible to interchange VDET coordinates on any of the four tracks from the B_S candidate without an unacceptably large increase in the χ^2 of the track fit. Removing the ITC and the TPC coordinates which contributed most to the χ^2 of the track fit changed the B_S mass by 0.0004 GeV. An interchange of the ambiguous hits in the ITC changed the B_S mass by 0.0001 GeV.

The alignment of the ALEPH tracking system has been studied using the $Z \to \mu^+\mu^-$ data. Single helix fits to this dimuon data show that there is a possibility of a ϕ dependent misalignment between the VDET and the ITC-TPC system. The amplitude of this effect is about 7 μm at the outer VDET layer. This could lead to an error on the track angle measurement of about $1.2 \cdot 10^{-4}$. Changing the measured ψ' and ϕ angles in opposite directions by this amount led to a change in the B_S mass of 0.0008 GeV. Studies of $Z \to \mu^+\mu^-$ events have also shown a charge-dependent bias in momentum measurement of 0.3%, implying an offset in track sagitta measurement of about $3.0 \cdot 10^{-7} cm^{-1}$. This offset contributes a mass measurement error of 0.0003 GeV. The sum, in quadrature, of all these sources of systematic error was 0.0015 GeV. Hence the B_S mass was measured to be

$$M_{Bs} \; = \; 5.3686 \; \pm \; 0.0056(stat.) \; \pm 0.0015(syst.) \; GeV.$$

Conclusion

In a sample of about 1.1 million hadronic Z decays recorded with the ALEPH detector, two unambiguous B_S meson candidates were completely reconstructed. From these events the measured B_S meson was $5.3686 \pm 0.0056(stat.) \pm 0.0015(syst.)$ GeV. This B_S meson mass is in good agreement with the predictions [7, 8] of the quark model. This is the first direct and precise measurement of the B_S meson mass.

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