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A measurement of the semileptonic branching ratio BR(b-baryon $\rightarrow$ p$l\bar{\nu}X$) and a study of inclusive $\pi^{\pm}$, $K^{\pm}$, (p, $\bar{p}$) production in Z decays

The ALEPH collaboration[1]

Abstract

Inclusive $\pi^{\pm}$, $K^{\pm}$ and $(p, \bar{p})$ production is investigated using data recorded by the ALEPH detector between 1992 and 1994. The momentum spectra and multiplicities are measured separately in $Z \rightarrow b\bar{b}$, $Z \rightarrow c\bar{c}$ and $Z \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$ decays. The number of protons found in b-hadron decays is used to estimate the fraction of b-baryons in b events to be $(10.2 \pm 0.7 \pm 2.7)\%$. From an additional study of proton-lepton correlations in b events the branching ratio BR(b-baryon $\rightarrow$ p$l\bar{\nu}X$) = $(4.63 \pm 0.72 \pm 0.98)\%$ is obtained. The ratio BR(b-baryon $\rightarrow$ p$l\bar{\nu}X$)/ BR(b-baryon $\rightarrow$ pX) is found to be $0.080 \pm 0.012 \pm 0.014$.

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1 Introduction

The long-standing discrepancy between theoretical predictions and measurements of the semileptonic branching ratio of heavy hadrons [1] may possibly be solved by calculations including higher-order corrections [2]. However, the puzzle of the different lifetimes of b-mesons and b-baryons remains. The ratio of lifetimes $\tau_{\text{b-baryon}}/\tau_{\text{B}^0}$ is predicted to be not smaller than 0.9 [3] while present measurements yield a value of 0.73 ± 0.08 [4]. Under the assumption that the semileptonic widths of all b-hadrons are the same this ratio can be probed independently by a measurement of the semileptonic branching ratio of b-baryons and mesons. Given the experimental measurements of lifetimes, a significantly smaller semileptonic branching ratio is expected for b-baryons than for b-mesons.

The measurement of the absolute branching ratio BR(b-baryon $\rightarrow$ p$l\bar{\nu}X$) is presented here.[2] Its evaluation requires the knowledge of the overall number of b-baryons and hence an estimate is made of the b-baryon fraction f_{Λ_b}, derived from proton production in b-hadron decays. The ratio $R_{\text{p}l}$ = BR(b-baryon $\rightarrow$ p$l\bar{\nu}X$)/BR(b-baryon $\rightarrow$ pX) is expected to be a good estimator for BR(b-baryon$\rightarrow lX$). This is compared with the overall semileptonic branching ratio BR(b $\rightarrow lX$) which is known more precisely than the corresponding branching ratio of any specific b-hadron state.

For the evaluation of f_{Λ_b}, b events are selected with help of a b-tag algorithm and protons are statistically identified by their specific energy loss in the detector. The main difficulty is to distinguish protons produced in b-hadron decay from those from fragmentation. The method used here is based on the impact parameter of the tracks and their angle with respect to the thrust axis. The two variables are independent and display good separation power between leading and non-leading particles.

In parallel to the search for protons from b decays, charged particle production is studied in Z $\rightarrow$ b$\bar{\text{b}}$, Z $\rightarrow$ c$\bar{\text{c}}$ and Z $\rightarrow$ u$\bar{\text{u}}$, d$\bar{\text{d}}$, s$\bar{\text{s}}$ events separately. The momentum spectra are measured for pions, kaons and protons and the corresponding mean multiplicities are calculated. These measurements are important to shed more light on the fragmentation of quarks and gluons into hadrons. At the same time the measurement of the rates and momentum spectra of particles produced in b-hadron decays helps to assure a correct description of the weak decay of b-hadrons in the Monte Carlo simulation.

The following sections describe the detector and its performance, event and track selection, particle identification with dE/dx, the selection of b decay particles, proton-lepton correlations and the systematic uncertainties of the analysis. Conclusions summarizing the results are given at the end of the paper.

[2] Charge conjugated modes are always included if not stated otherwise.

2 The detector

The ALEPH detector is described in detail elsewhere [5, 6] and only a brief overview of the most relevant parts for this analysis is given here.

The momentum of charged particles is measured in three concentric tracking chambers. The innermost is the vertex detector consisting of two layers of double sided silicon microstrips with radii of 6.5 cm and 11.3 cm, respectively. The spatial resolution for the $r\phi$ and z projections is 12 μm at normal incidence. The vertex detector is surrounded by the inner drift chamber (ITC) with eight coaxial wire layers. Outside the ITC the time projection champer (TPC) provides up to 21 three-dimensional space points per track. The TPC has inner and outer radii of 30 and 180 cm and is 2.2 m long. The three tracking detectors are placed within a superconducting solenoid providing a magnetic field of 1.5 T, and together give a transverse momentum resolution of $\sigma(p)/p = 6 \times 10^{-4} p$ for high momentum tracks (p in GeV/c). The TPC also provides up to 338 measurements of the ionization loss of a track and is essential for the identification of charged particles. The specific energy loss $\mathrm{d}E/\mathrm{d}x$ is estimated from the truncated mean of the usable samples associated with a track, discarding the lower 8% and upper 40% of the samples. For an electron with the full complement of measurements at a polar angle of $\Theta = 45^\circ$ a resolution of 4.5% is achieved. About 88% of all tracks have at least 50 $\mathrm{d}E/\mathrm{d}x$ samples. A more detailed description of the ALEPH $\mathrm{d}E/\mathrm{d}x$ measurement can be found in [6] and [7].

The TPC is surrounded by a lead/proportional-chamber electromagnetic calorimeter segmented into $0.9^\circ \times 0.9^\circ$ projective towers and read out in three sections in depth with an energy resolution of $\sigma(E)/E = 0.18/\sqrt{E} + 0.009$ (E in GeV). In the electromagnetic calorimeter electrons and photons can be identified by their characteristic longitudinal and transverse shower developments. The iron return yoke of the magnet is instrumented with streamer tubes to form a hadron calorimeter and is surrounded by two additional double layers of streamer tubes to aid in muon identification.

The interaction point is reconstructed on an event-by-event basis using the constraint of the average beam spot position [6] resulting in an average resolution of 85 μm for $\mathrm{Z} \to \mathrm{b\bar{b}}$ events, projected along the sphericity axis of the event.

3 Event and track selection

The data used in this analysis were recorded by the ALEPH detector during the years 1992 – 1994. The selection of hadronic events is based on charged tracks and is described elsewhere [8]. Only events with a thrust axis fulfilling $|\cos\theta_{thrust}| < 0.85$ are taken into account leading to about 2.3 million selected hadronic Z decays. Further cuts are applied on the quality of the tracks in these events. Each track must have at least four measured points in the TPC and at

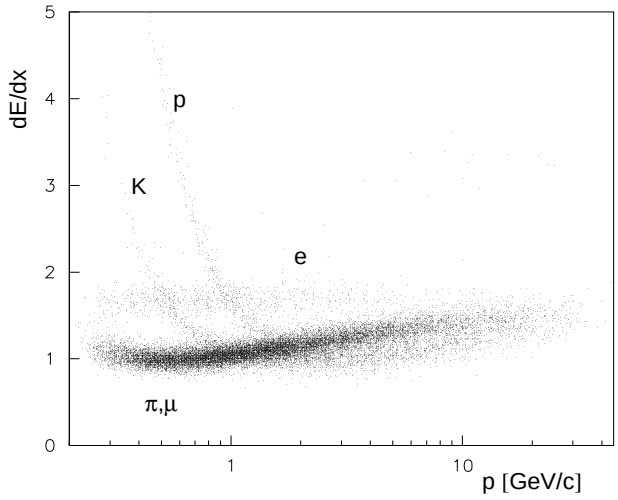

Figure 1: *The mean dE/dx of a sample of 20 000 tracks as a function of their momentum. The energy loss of minimal ionizing particles is normalized to one.*

least 125 single $\mathrm{d}E/\mathrm{d}x$ measurements. The tracks must originate from within a cylinder of radius 2 cm and length 20 cm centred on the nominal interaction point. The polar angle of the tracks must satisfy $|\cos\theta_{track}| < 0.85$ and a minimum momentum of 300 MeV/c is required. To avoid protons from interactions with the detector material only negatively charged tracks are selected for momenta lower than 3 GeV/c.

4 Particle identification

Charged particles are identified by their specific energy loss in the TPC. Figure 1 shows the truncated mean $\mathrm{d}E/\mathrm{d}x$ as a function of the momentum for selected tracks from hadronic events. The number of pions, kaons and protons are obtained from the tracks' $\mathrm{d}E/\mathrm{d}x$ distribution by means of an extended maximum likelihood fit. The probability density for a given particle with a measured energy loss $\mathrm{d}E/\mathrm{d}x$ under the particle hypothesis $j = \pi, \mathrm{K}, \mathrm{p}, \mathrm{e}, \mu$ has been parametrized in a similar way to [7] but for this analysis a 'bifurcated' Gaussian has been used to allow a better description of the asymmetric tails of the $\mathrm{d}E/\mathrm{d}x$ distribution:

$$G^j(\mathrm{d}E/\mathrm{d}x) = \frac{2}{\sqrt{2\pi}(\sigma_+ + \sigma_-)} \exp\left(-\frac{(\mathrm{d}E/\mathrm{d}x - \langle \mathrm{d}E/\mathrm{d}x\rangle^j_{\mathrm{exp}})^2}{2\sigma^2_\pm}\right), \qquad (1)$$

with $\sigma_\pm = \sigma_-$ for $\mathrm{d}E/\mathrm{d}x < \langle \mathrm{d}E/\mathrm{d}x\rangle^j_{\mathrm{exp}}$ and $\sigma_\pm = \sigma_+$ for $\mathrm{d}E/\mathrm{d}x \geq \langle \mathrm{d}E/\mathrm{d}x\rangle^j_{\mathrm{exp}}$, while $\langle \mathrm{d}E/\mathrm{d}x\rangle^j_{\mathrm{exp}}$ stands for the expected energy loss under the particle hypothesis j. The σ_+ and σ_- are parametrized as

$$\sigma_+/\langle \mathrm{d}E/\mathrm{d}x\rangle_{\mathrm{exp}} = A\sigma_-/\langle \mathrm{d}E/\mathrm{d}x\rangle_{\mathrm{exp}} = \sigma_0 {n_s}^{p_1} l^{p_2} (\langle \mathrm{d}E/\mathrm{d}x\rangle_{\mathrm{exp}})^{p_3}, \qquad (2)$$

with A being a free parameter in the likelihood fit (which in general is found to be close to one). Here, n_s is the number of single $\mathrm{d}E/\mathrm{d}x$ measurements, and l is the normalized mean sample length per measurement. The exponents p are expected to be close to 0.5 [9]. Together with σ_0 they were determined to be $p_1 = -0.5$, $p_2 = p_3 = -0.4$ and $\sigma_0 = 0.82$ from identified, low momentum particles [6]. The expected energy loss per unit length $\langle \mathrm{d}E/\mathrm{d}x \rangle^j_{\mathrm{exp}}$ is given by the Bethe-Bloch formula [10], a parametrization of which was fit to the ALEPH data from all particles in the low β region and from pions at higher momenta. Muons are not distinguished in the fit as their fraction is small with respect to the pions and hence it is fixed to the Monte Carlo prediction. The introduced uncertainties, mainly on the pion rates, are minor.

For the complete likelihood, the probability density is first summed over all possible particle types weighted with the corresponding particle fractions f_j (which are – together with A – the free parameters in the likelihood fit). Then the probabilities of all tracks are multiplied:

$$\mathcal{L} = \frac{e^{-\phi}\phi^N}{N!} \prod_{i=1}^{N} (\sum_j f_j G_i^j(dE/dx^i, \langle dE/dx \rangle^{ji}_{\mathrm{exp}}, \sigma_{ji})). \tag{3}$$

The Poisson factor in front represents the probability of obtaining a sample of size N from a distribution of mean ϕ, where ϕ is an additional free parameter in the fit. The sum of the particle fractions is constrained to one.

Some examples of the likelihood fit results are shown in Fig. 2 to illustrate the quality.

5 π , K and proton production

5.1 Decomposition of the track samples

All selected events are divided into two hemispheres, defined by the plane perpendicular to the thrust axis. On each hemisphere a b-tag is applied giving the probability for this hemisphere to contain only tracks from the primary vertex. The performance of the b-tag is described in detail in [11]. Five intervals of the b-tag variable are defined and all tracks are assigned to one of these intervals according to the b-tag result of the opposite hemisphere in the same event. (The opposite hemisphere is used to minimize a possible bias introduced by the b-tag.) Using the tracks in each subsample the likelihood fit gives the number of pion, kaons and protons for 50 different momentum bins. The composition of the particles regarding their origin can be described for each of the five samples i by:

$$N_j^i = \epsilon^i_{\mathrm{b}} N_j^{\mathrm{b}} + \epsilon^i_{\mathrm{c}} N_j^{\mathrm{c}} + \epsilon^i_{\mathrm{uds}} N_j^{\mathrm{uds}} \qquad j = \pi, \mathrm{K}, \mathrm{p};\ \mathrm{i} = 1 \ldots 5, \tag{4}$$

where N_j^{b}, N_j^{c} and N_j^{uds} are the (unknown) number of pions, kaons or protons in b, c, and uds hemispheres and ϵ^i_{b}, ϵ^i_{c} and $\epsilon^i_{\mathrm{uds}}$ are the fractions of b, c and uds

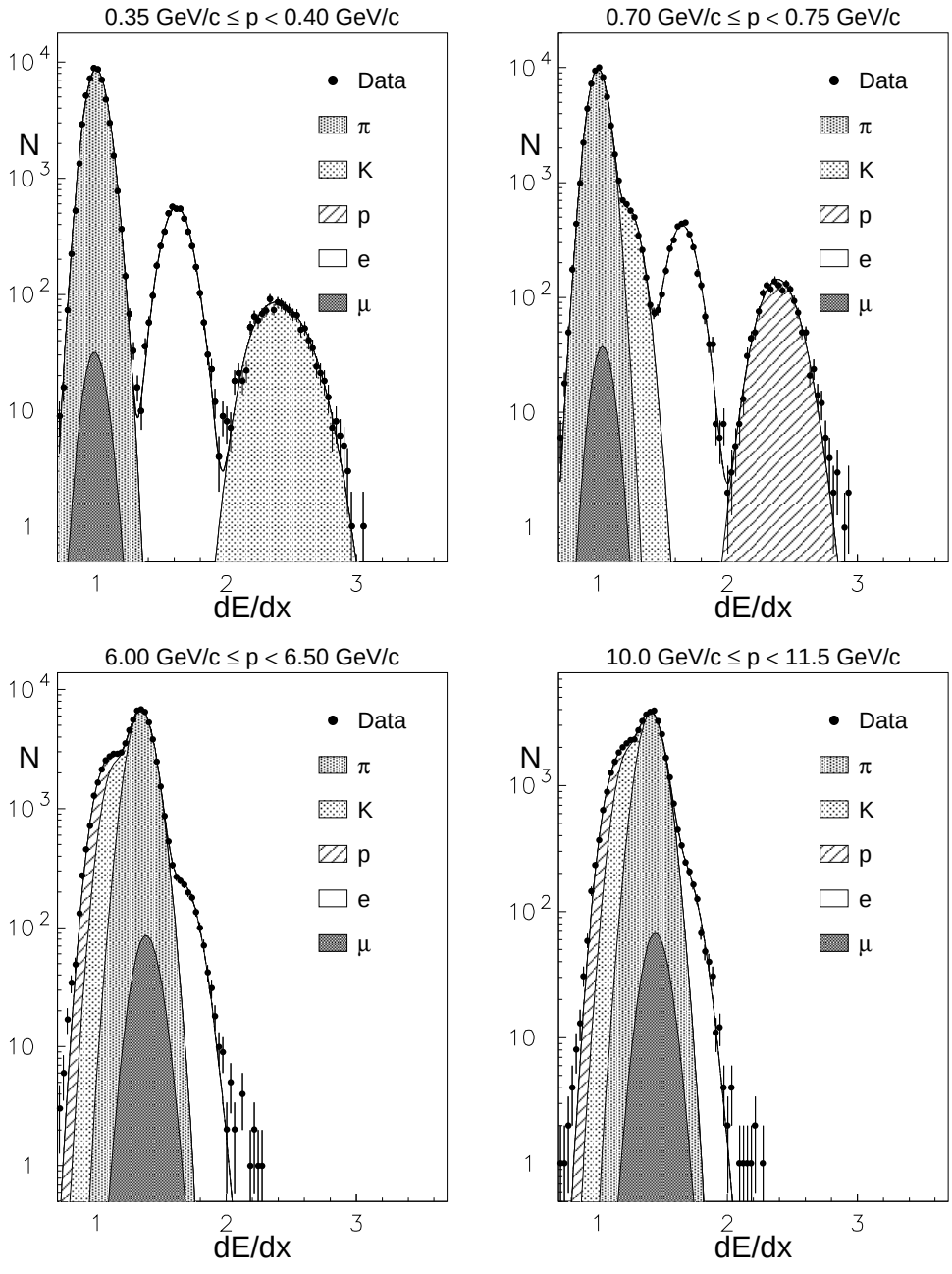

Figure 2: *Specific energy loss of selected particles together with the likelihood fit result in different momentum bins. The full dots represent the data, the hatched regions indicate the different particle fractions and the line is the overall fit function.*

hemispheres which fall in the b-tag interval i. Almost all the fractions ϵ^i can be derived from data following closely the method described in [11]. To do this the number of hemispheres $N^{H\,i}$, within a specific b-tag interval i, can be written as

$$N^{H\,i} = (\epsilon^i_{\rm b} R_{\rm b} + \epsilon^i_{\rm c} R_{\rm c} + \epsilon^i_{\rm uds} R_{\rm uds}) N^H_{\rm tot}, \tag{5}$$

with $N^H_{\rm tot}$ being the total number of hemispheres, $R_{\rm b}$ the ratio of partial widths $\Gamma_{\rm Z\to b\bar{b}}/\Gamma_{\rm Z\to hadrons}$ and with $R_{\rm c}$ and $R_{\rm uds}$ being defined analogously to $R_{\rm b}$. The number of events with both hemispheres in the same interval i is then given by

$$N^{E\,i} = (\epsilon^{D\,i}_{\rm b} R_{\rm b} + \epsilon^{D\,i}_{\rm c} R_{\rm c} + \epsilon^{D^i}_{\rm uds} R_{\rm uds}) N^E_{\rm tot}, \tag{6}$$

with $\epsilon^{D\,i} = \lambda^i \epsilon^{i\,2}$ taking account of the correlation between the two hemispheres (of the order of 10%) by means of the factors λ^i. The λ^i values are taken from simulations. With the partial decay widths of the Z fixed to their Standard Model predictions and the constraint $\sum_i \epsilon^i_{\rm flav} = 1$ almost all fractions can be calculated from data. Only the three least significant (of fifteen) are fixed to their Monte Carlo predictions.

The number of pions, kaons and protons in $\rm Z \to b\bar{b}$, $\rm Z \to c\bar{c}$ and $\rm Z \to u\bar{u}, d\bar{d}, s\bar{s}$ ($N^{\rm b}_j$, $N^{\rm c}_j$, $N^{\rm uds}_j$) is calculated from Eq. 4 for each momentum bin. The resulting momentum spectra are given in Fig. 7 to 9. They have been corrected for the effects of geometrical acceptance, track reconstruction efficiency and interactions in the material of the detector, using an event generator based on the DYMU [12] and JETSET 7.3 [13] programs, in which the decay properties of heavy flavour hadrons were significantly extended. The spectra are normalized to the number of hadronic Z decays and are the weighted mean of the three years of data taking. The expectations of the Monte Carlo, which was tuned to reproduce global event shape and charged particle inclusive distributions [14], are indicated by the overlaid curves. The 'holes' in the spectra correspond to those momentum regions where the $\mathrm{d}E/\mathrm{d}x$ distributions of different particle types overlap so heavily that the fit is no longer sensitive to those particle fractions. These regions were excluded from the analysis. In the appendix the spectra are given in tabular form, a computer readable form can be found at [15].

To measure the number of particles from b-hadron decays the track samples are further classified. Within each of the five b-tag intervals the tracks are divided into four classes: tracks with positive impact parameter, tracks with negative impact parameter, tracks with $|\cos\alpha| > 0.975$, where α is the angle between track and thrust axis, and tracks with $|\cos\alpha| < 0.975$. This leads to 20 different samples and hence to 20 equations per particle type, describing the particle composition. In the following the index j is omitted for simplicity:

$$\begin{aligned} N^{i,\rm class} \;=\; & \epsilon^i_{\rm b}(\epsilon^{\rm class}_{\rm bdecay} N^{\rm b}_{\rm bdecay} + \epsilon^{\rm class}_{\rm accomp} N^{\rm b}_{\rm accomp}) \\ & + \epsilon^i_{\rm c} \epsilon^{\rm class}_{\rm c} N^{\rm c} \\ & + \epsilon^i_{\rm uds} \epsilon^{\rm class}_{\rm uds} N^{\rm uds}, \end{aligned} \tag{7}$$

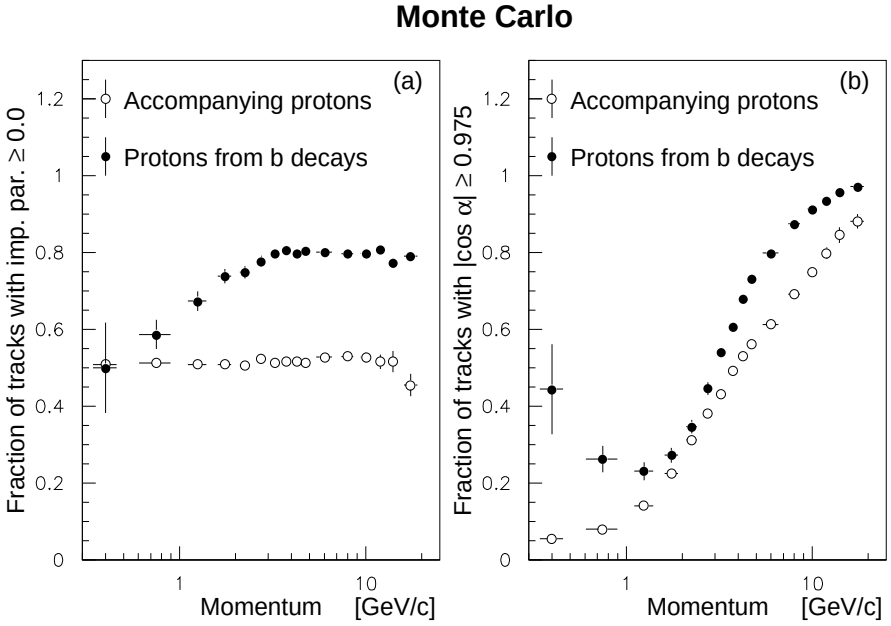

Figure 3: *(a) the fraction of protons with positive impact parameter depending on origin and momentum of the particle as predicted from Monte Carlo simulations of b-hadron decays. (b) the same for the fraction of protons with* $|\cos\alpha| > 0.975$.

where $N^{i,\mathrm{class}}$ is the overall number of particles in the b-tag interval i fulfilling requirement 'class' (positive/negative impact parameter,$|\cos\alpha| < 0.975/ > 0.975$) and $N^{\mathrm{b}}_{\mathrm{bdecay}}$, $N^{\mathrm{b}}_{\mathrm{accomp}}$, N^{c} and N^{uds} are the number of particles from b decays, accompanying the b-hadron in b events, and the number in c events and uds events. The fraction of particles from b decays satisfying the criteria 'class' is indicated by $\epsilon^{\mathrm{class}}_{\mathrm{bdecay}}$, while $\epsilon^{\mathrm{class}}_{\mathrm{accomp}}$, $\epsilon^{\mathrm{class}}_{\mathrm{uds}}$ and $\epsilon^{\mathrm{class}}_{\mathrm{c}}$ are defined analogously. All these fractions are taken from Monte Carlo simulations. Then $N^{\mathrm{b}}_{\mathrm{bdecay}}$ and $N^{\mathrm{b}}_{\mathrm{accomp}}$ can be calculated from Eqs. 4 and 7 if the difference between $\epsilon^{\mathrm{class}}_{\mathrm{bdecay}}$ and $\epsilon^{\mathrm{class}}_{\mathrm{accomp}}$ is sizeable. The separation power of the two variables is shown in Fig. 3. In Fig. 3 (a) the fractions of protons with positive impact parameter are given for b-hadron decays and accompanying the b-hadron. Figure 3 (b) shows the discrimination on the basis of $|\cos\alpha| > 0.975$.

After performing the likelihood fit for each sample the numbers of pions, kaons and protons from b-hadron decays and accompanying the b-hadrons are calculated from Eq. 7 for all momentum bins. The resulting spectra are shown in Fig. 10 and 11. Below 1 GeV/c the small number of protons from b decays is not accessible because of the high background from fragmentation protons.

5.2 Multiplicities

The momentum spectra of pions, kaons and protons in $Z \to b\bar{b}$, $Z \to c\bar{c}$, $Z \to u\bar{u}, d\bar{d}, s\bar{s}$ events, in b-hadron decays and accompanying the b-hadron in b events are shown in Figs. 7 to 11. After extrapolating the spectra with help of the simulation over the full kinematic range the corresponding mean multiplicities can be calculated. They are given in tables 1 to 3.

origin	$\pi^{\pm}$				
$Z \to q\bar{q}$	17.04	$\pm$	0.005_{stat}	$\pm$	0.31_{sys}
$Z \to uds$	16.86	$\pm$	0.02_{stat}	$\pm$	0.52_{sys}
$Z \to c\bar{c}$	15.93	$\pm$	0.07_{stat}	$\pm$	1.31_{sys}
$Z \to bb$	18.44	$\pm$	0.03_{stat}	$\pm$	0.63_{sys}
b decay	3.97	$\pm$	0.02_{stat}	$\pm$	0.21_{sys}

Table 1: *Pion multiplicities in Z and b-hadron decays*

origin	$K^{\pm}$				
$Z \to q\bar{q}$	2.26	$\pm$	0.002_{stat}	$\pm$	0.12_{sys}
$Z \to uds$	2.14	$\pm$	0.008_{stat}	$\pm$	0.13_{sys}
$Z \to c\bar{c}$	2.44	$\pm$	0.03_{stat}	$\pm$	0.23_{sys}
$Z \to bb$	2.63	$\pm$	0.008_{stat}	$\pm$	0.14_{sys}
b decay	0.72	$\pm$	0.020_{stat}	$\pm$	0.06_{sys}

Table 2: *Kaon multiplicities in Z and b-hadron decays*

origin	$p, \bar{p}$				
$Z \to q\bar{q}$	1.00	$\pm$	0.002_{stat}	$\pm$	0.07_{sys}
$Z \to uds$	1.04	$\pm$	0.006_{stat}	$\pm$	0.07_{sys}
$Z \to c\bar{c}$	0.87	$\pm$	0.02_{stat}	$\pm$	0.10_{sys}
$Z \to bb$	1.00	$\pm$	0.007_{stat}	$\pm$	0.08_{sys}
b decay	0.131	$\pm$	0.004_{stat}	$\pm$	0.011_{sys}

Table 3: *Proton multiplicities in Z and b-hadron decays*

A comparison with results from other e^+e^- experiments can be found in tables 4, 5 and 6. In all cases the agreement is very good. The proton production in b-hadron decays as measured at LEP is found to differ significantly from the $\Upsilon(4S)$ value. This is due to b-baryon production on the Z resonance.

Mean multiplicities in $Z \to q\bar{q}$			
	this analysis	DELPHI	OPAL
$\pi^{\pm}$	17.04 ± 0.31	—	17.05 ± 0.43
$K^{\pm}$	2.26 ± 0.12	2.26 ± 0.18	2.42 ± 0.13
$p, \bar{p}$	1.00 ± 0.07	1.07 ± 0.14	0.92 ± 0.11

Table 4: *Mean multiplicity of different particles in comparison with* DELPHI *[16] and* OPAL *[17].*

Mean multiplicities in $Z \to b\bar{b}$		
	this analysis	DELPHI
$\pi^{\pm}$	18.44 ± 0.63	—
$K^{\pm}$	2.63 ± 0.14	2.74 ± 0.50
$p, \bar{p}$	1.00 ± 0.08	1.13 ± 0.27

Table 5: *Mean multiplicities of different particles in $Z \to b\bar{b}$ in comparison with* DELPHI *results [18].*

Mean multiplicities in b-hadron decays			
	this analysis	DELPHI	ARGUS/CLEO
$\pi^{\pm}$	3.97 ± 0.21	—	4.11 ± 0.08
$K^{\pm}$	0.72 ± 0.06	0.88 ± 0.19	0.78 ± 0.03
$p, \bar{p}$	0.131 ± 0.011	0.141 ± 0.059	0.08 ± 0.004

Table 6: *Mean multiplicities of pions, kaons and protons in b-hadron decays in comparison to* DELPHI *measurements [18] and to measurements by* ARGUS *and* CLEO *in $\Upsilon(4S)$ decays [4]. In contrast to Z decays only $B^{\pm}$ and B^0 are produced there, leading to a significant lower proton production from b decays.*

Adding the lepton multiplicity in b decays from $\mathrm{Br}(b \to lX)$, $\mathrm{Br}(b \to c \to lX)$ [19] and $\mathrm{Br}(b \to c\bar{c}s \to lX)$ [20] to the multiplicites of pions, kaons and protons in table 6 the mean multiplicity of charged hadrons in b decays is found to be

$$\langle n_b \rangle = 5.24 \pm 0.25 \ . \tag{8}$$

The result is dominated by systematics and can be compared with measurements of DELPHI [18] and OPAL [21] which gave $\langle n_b \rangle = 5.84 \pm 0.38$ and 5.51 ± 0.51, respectively.

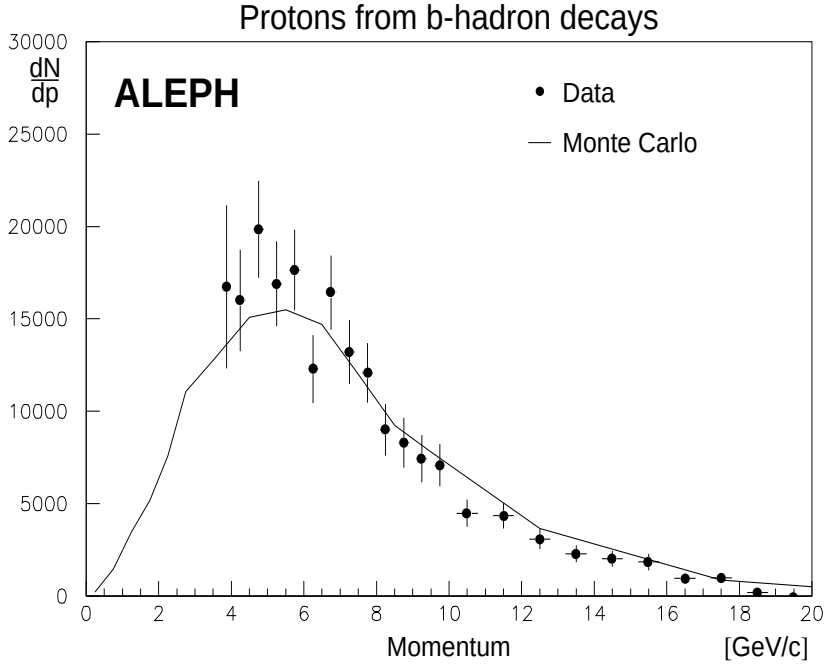

Figure 4: *Momentum spectra for protons from b decays: data and Monte Carlo prediction. The Monte Carlo is normalized to the data.*

5.3 The b-baryon fraction f_{Λ_b}

The overall number of protons from b-hadron decay is used to estimate the b-baryon fraction f_{Λ_b}. Assuming that BR(b-baryon $\to$ pX) is considerably larger than BR(b-meson $\to$ pX) even a small fraction of b-baryons will lead to a sizeable increase of protons in b-hadron decays with respect to the pure meson sample, as e.g. in Υ(4S) decays.

The number of protons from b-hadron decays N_p is related to the b-baryon fraction as follows

$$N_p = (f_{\Lambda_b}\mathrm{BR(b\text{-}baryon} \to \mathrm{p}X) + (1 - f_{\Lambda_b})\mathrm{BR(b\text{-}meson} \to \mathrm{p}X))N_b \qquad (9)$$

with the number of b-hadron decays N_b being calculated from the overall number of events multiplied by $2R_b$ (using the Standard Model value for R_b). The equation can be solved for f_{Λ_b}

$$f_{\Lambda_b} = \frac{N_p/N_b - \mathrm{BR(b\text{-}meson} \to \mathrm{p}X)}{\mathrm{BR(b\text{-}baryon} \to \mathrm{p}X) - \mathrm{BR(b\text{-}meson} \to \mathrm{p}X)} \ . \qquad (10)$$

To extract N_p the measured momentum spectra of b decay protons is extrapolated from 3.75 GeV/c to zero using the Monte Carlo prediction as indicated in Fig. 4. The branching ratio BR($B^{\pm}, B^0 \to pX$) has been measured at the Υ(4S) by ARGUS and CLEO to be $(8.0 \pm 0.4)\%$ [4] but BR($B_s \to pX$) is unknown. As a conservative estimate BR($B_s \to pX$) $= (8.0 \pm 4.0)\%$ has been assumed. The B_s fraction in b events was taken from [4].

Because no measurements are available for BR(b-baryon $\to$ pX) it has to be estimated. Naively BR(b-baryon $\to$ pX) is close to BR(b-baryon $\to$ nX) and hence about 50%. But this assumption does not fully hold true, taking e.g. isospin arguments and the decay via Λ or Σ particles into account which lead to different branching ratios into protons and neutrons. As an upper limit it has been assumed that all b-baryon decays produce a Λ and therefore BR(b-baryon $\to$ pX) = 64%. For a lower estimate BR(b-baryon $\to \Lambda X$) = BR(b-baryon $\to \Sigma^+ X$) = BR(b-baryon $\to \Sigma^0 X$) = BR(b-baryon $\to \Sigma^- X$) = 25% has been assumed. This results in BR(b-baryon $\to$ pX) = 45%. The mean value is (54.5 ± 5.5)%, the error is taken from the standard deviation of a uniform probability distribution. However there are also b-baryon decays with three baryons in the final state. The branching ratio for these is taken from the Monte Carlo prediction and adds 3% to the above estimate with an assumed relative uncertainty of 50%. Hence BR(b-baryon $\to$ pX) = (58 ± 6)% has been used for the calculation of the b-baryon fraction. The result is

$$f_{\Lambda_b} = (10.2 \pm 0.7_{\text{stat}} \pm 2.2_{\text{sys1}} \pm 1.6_{\text{sys2}})\%. \tag{11}$$

Here the first systematic error represents uncertainties related to the analysis and the second uncertainties related to the branching ratios. The systematic uncertainties of the measurement are discussed in section 7. The resulting baryon fraction can be compared to the value (13.2 ± 4.1)% calculated from BR(b-baryon $\to \Lambda_c l \bar{\nu} X$) and the b-baryon lifetime [4] and is found to be in good agreement.

6 Proton-lepton correlation

For the search for proton-lepton[3] pairs from b-baryon decays the analysis is restricted to events containing a high momentum lepton candidate. (The selection of leptons within ALEPH is discussed in [19] and [22].) For this analysis only tracks with opposite charge with respect to the lepton candidate are selected and the angle between the track and the thrust axis is not used because of possible correlations with the transverse momentum of the lepton. The selection cuts for the tracks are slightly released to gain efficiency and no b-tag is performed. The presence of a high momentum lepton candidate sufficiently enriches the event sample with b events.

The impact parameter of the proton candidates is again used to measure their number in b decays while the p_T of the lepton with respect to the jet axis is used to identify the proton-lepton pairs from b-baryons and distinguish them from background processes. Possible background sources for proton-lepton pairs are listed below:

[3] 'lepton' stands for electron or muon

Composition of the proton-lepton pair sample	
Source	number per b-baryon decay
b-baryon decays	free parameter
$\mathrm{b} \to \mathrm{c\bar{c}s}, \bar{\mathrm{c}} \to l\bar{\nu}X$	0.012
$\mathrm{b} \to \tau\bar{\nu}\mathrm{p}X,\ \tau \to l\bar{\nu}\nu$	0.002
b-meson $\to \Lambda_\mathrm{c}\bar{\mathrm{p}}X,\ \Lambda_\mathrm{c} \to l\bar{\nu}X$	free parameter
b-meson $\to \bar{\mathrm{p}}l\bar{\nu}X$	free parameter
$\mathrm{b} \to \mathrm{p}X+$ fake lepton	free parameter

Table 7: *Composition of the proton lepton sample where the protons come from b-hadron decay. As indicated two contributions are fixed within the analysis, the others are left free.*

1. Decay of the b quark into $\mathrm{c\bar{c}s}$ with subsequent semileptonic $\bar{\mathrm{c}}$ quark decay in l^-X. An example is the decay $\Lambda_\mathrm{b} \to \bar{\mathrm{D}}_\mathrm{s}\mathrm{p}X,\ \bar{\mathrm{D}}_\mathrm{s} \to l^-X$. Using $\mathrm{BR}(\mathrm{b} \to \mathrm{c\bar{c}s},\ \bar{\mathrm{c}} \to lX) = (1.3 \pm 0.5)\%$ [20] and $\mathrm{BR}(\text{b-baryon} \to \mathrm{p}X) \approx 58\%$ about 0.8% of all b-baryons are expected to contribute to this background. A similar assumption for mesons with $\mathrm{BR}(\text{b-meson} \to \mathrm{p}X) = 8.0\%$ leads to approximately 0.004 background events per b-baryon.

2. b-baryon $\to \mathrm{p}\tau X$ with subsequent leptonic decay of the τ lepton. From the known branching ratio of $\mathrm{b} \to \tau X$ one can conclude that about 0.17% of all b-baryons contribute to this background source.

3. b-meson $\to \Lambda_\mathrm{c}\bar{\mathrm{p}}X$ followed by a semileptonic decay of the Λ_c.

4. b-meson $\to \bar{\mathrm{p}}lX$.

5. The lepton is produced in pion or kaon decays, in photon conversion or is a misidentified hadron. In the following these will be called 'fake leptons'.

All background processes (which are summarized in table 7) show considerably softer lepton p_T spectra than the signal process.

Eight data sets are selected. Four intervals, based on the p_T of the lepton candidate, 0.0 and 0.5 GeV/c, 0.5 and 0.8 GeV/c, 0.8 and 1.2 GeV/c and greater than 1.2 GeV/c are chosen and then each set is divided further into one sample containing tracks with positive impact parameters and one containing tracks with negative impact parameters. The number of protons in each sample can be written as:

$$\begin{aligned} N^{\mathrm{p}l}_{\hat{p_T},+} &= \epsilon^+_\mathrm{b}\Big(\sum_x \epsilon^x_{\hat{p_T}} N^x_{\mathrm{p}l}\Big) + \epsilon^+_{\text{non-b}} N^{\text{non-b}}_{\hat{p_T}} \\ N^{\mathrm{p}l}_{\hat{p_T},-} &= \epsilon^-_\mathrm{b}\Big(\sum_x \epsilon^x_{\hat{p_T}} N^x_{\mathrm{p}l}\Big) + \epsilon^-_{\text{non-b}} N^{\text{non-b}}_{\hat{p_T}}, \end{aligned} \tag{12}$$

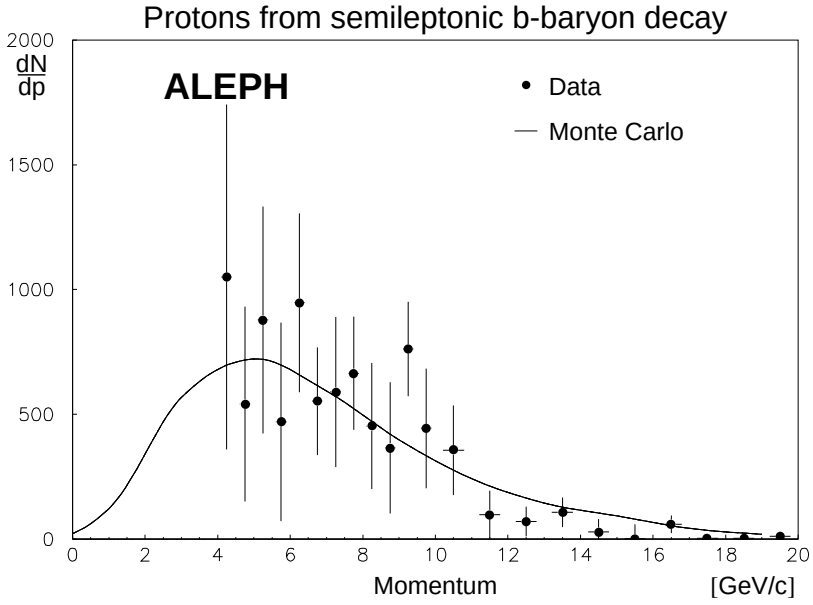

Figure 5: *The momentum spectrum of protons from semileptonic b-baryon decay (electrons and muons). The dots represent the data, the line the Monte Carlo prediction, normalized to the data*

with $N^{\mathrm{p}l}_{\hat{p_T},+}$ being the measured number of proton-lepton pairs with a transverse momentum of the lepton candidate in the p_T interval $\hat{p_T}$ and a proton with positive impact parameter, $N^{\mathrm{p}l}_{\hat{p_T},-}$ is defined analogously but contains protons with negative impact parameters. The numbers of proton-lepton pairs from the different sources x (b-baryon decay or one of the background processes described above) are denoted $N^x_{\mathrm{p}l}$ and are calculated together with the numbers of proton-lepton pairs $N^{\text{non-b}}_{\hat{p_T}}$ where the proton does not come from any b decay but the lepton candidate has a p_T in the interval $\hat{p_T}$. The probability that a lepton from source x has a transverse momentum in the p_T interval $\hat{p_T}$ is written as $\epsilon^x_{\hat{p_T}}$. These numbers are taken from Monte Carlo. The fraction of protons from b-hadron decays having a positive impact parameter is denoted ϵ^+_{b} with $\epsilon^+_{\text{non-b}}$, ϵ^-_{b} and $\epsilon^+_{\text{non-b}}$ defined analogously. To solve the equations two background contributions are fixed to the expected values given in table 7. The number of protons from b-baryon decays can then be calculated in each momentum bin. The result is given in Fig. 5. Extrapolating the spectrum to zero using Monte Carlo leads to

$$f_{\Lambda_{\mathrm{b}}}\mathrm{BR}(\text{b-baryon} \to \mathrm{p}l\bar{\nu}X) = (4.72 \pm 0.66_{\mathrm{stat}} \pm 0.44_{\mathrm{sys}})10^{-3} \; . \qquad (13)$$

This number is the average of l = *electron* and l = *muon* and can be compared with a measurement of DELPHI [23]: $f_{\Lambda_{\mathrm{b}}}\mathrm{BR}(\text{b-baryon} \to \mathrm{p}\mu X) = (4.9 \pm 1.1 \pm 1.3)10^{-3}$. Together with $f_{\Lambda_{\mathrm{b}}}$ from Eq. 11 an absolute branching ratio can be calculated:

$$\mathrm{BR}(\text{b-baryon} \to \mathrm{p}l\bar{\nu}X) = (4.63 \pm 0.72_{\mathrm{stat}} \pm 0.68_{\mathrm{sys1}} \pm 0.71_{\mathrm{sys2}})\% \; . \qquad (14)$$

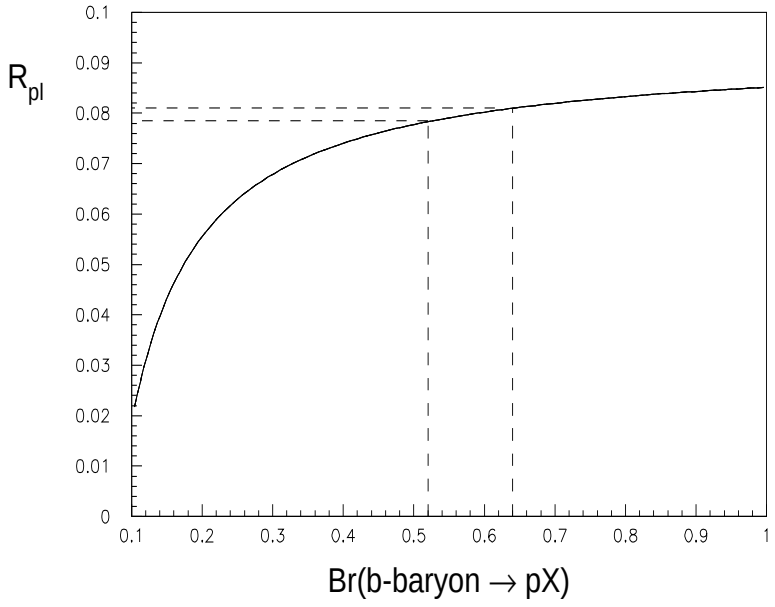

Figure 6: *The dependence of R_{pl} on $BR(b\text{-baryon} \to pX)$. R_{pl} varies only slightly with $BR(b\text{-baryon} \to pX)$ over a wide range. Allowing $BR(b\text{-baryon} \to pX)$ to vary between 0.52 and 0.64, R_{pl} changes only about 0.003. Towards smaller $BR(b\text{-baryon} \to pX)$ the dependence increases significantly.*

One of the major uncertainties of this result is the estimate of BR(b-baryon $\to$ pX). However, the ratio $R_{\rm pl}$ = BR(b-baryon $\to$ p$l\bar{\nu}X$)/BR(b-baryon $\to$ pX) is only slightly dependent on this quantity as indicated in Fig. 6. $R_{\rm pl}$ is found to be

$$R_{\rm pl} = \frac{\rm BR(b\text{-baryon} \to p\it l\bar{\nu}X)}{\rm BR(b\text{-baryon} \to pX)} = 0.080 \pm 0.012_{\rm stat} \pm 0.014_{\rm sys} \ . \qquad (15)$$

Assuming that

$$\frac{\rm BR(b\text{-baryon} \to p\it l\bar{\nu}X)}{\rm BR(b\text{-baryon} \to \it lX)} \approx \rm BR(b\text{-baryon} \to pX) \qquad (16)$$

the ratio $R_{\rm pl}$ is close to BR(b-baryon $\to$ lX) and can be compared with the recent OPAL measurement [24] of $R_{\Lambda l} = 0.070 \pm 0.012 \pm 0.007_{\rm sys}$, with $R_{\Lambda l}$ = BR(b-baryon $\to$ $\Lambda l\bar{\nu}X$)/BR(b-baryon $\to$ ΛX), which is in very good agreement.

If

$$\frac{\tau_{\rm b\text{-}baryon}}{\tau_{\rm b}} \approx \frac{\rm BR(b\text{-baryon} \to \it lX)}{\rm BR(b \to \it lX)} \qquad (17)$$

and $R_{\rm pl} \approx$ BR(b-baryon $\to$ lX) one can compare the ratio of the semileptonic branching ratios of b-baryons and all b-hadrons

$$\frac{R_{\rm pl}}{\rm BR(b \to \it lX)} = 0.72 \pm 0.17 \qquad (18)$$

with the corresponding ratio of lifetimes, calculated from [4]:

$$\frac{\tau_{\text{b-baryon}}}{\tau_{\text{b}}} = 0.74 \pm 0.05 \ . \tag{19}$$

The agreement is again very good. The branching ratio BR(b $\to lX$) in Z decays has been taken from [4].

7 Systematics

Several sources of systematic uncertainties affect the accuracy of the measurements. They are listed in table 8 and 9 together with the uncertainties due to the limited knowledge of the branching ratios BR(b-baryon $\to$ pX) and BR(b-meson $\to$ pX).

The fitted particle rates depend crucially on the expected dE/dx values and resolutions entering the likelihood function. Therefore the expected dE/dx are shifted within the uncertainties of the parametrization of the Bethe-Bloch formula (section 4). The resolution is rescaled and a Gaussian is used instead of a 'bifurcated' Gaussian. In the overlap region the added uncertainties are 0.9%, 4% and 6.5% for pions, kaons and protons, respectively. The deviations of subsequent bins are correlated and conservatively all momentum bins within the overlap region are taken as 100 % correlated.

The sign of a track's impact parameter and its angle with the thrust axis are used to distinguish particles from b-hadron decay from accompanying particles and hence the result relies on the correct simulation of these two quantities. Two checks are performed: First no distinction is made between decay and fragmentation particles. Equation system 7 then reduces to:

$$\begin{aligned} N_{\text{all,i}} &= \epsilon^i_{\text{b}} N_{\text{b}} + \epsilon^i_{\text{c}} N_{\text{c}} + \epsilon^i_{\text{uds}} N_{\text{uds}} \\ N^{\text{class}}_{\text{all,i}} &= \epsilon^{\text{class}}_{\text{b}} \epsilon^i_{\text{b}} N_{\text{b}} + \epsilon^{\text{class}}_{\text{c}} \epsilon^i_{\text{c}} N_{\text{c}} + \epsilon^{\text{class}}_{\text{uds}} \epsilon^i_{\text{uds}} N_{\text{uds}} \ . \end{aligned} \tag{20}$$

Here the fractions ϵ^{class} can be measured directly from the data and be compared with the predictions. At very low (high) momentum ϵ^{class} is very close to $\epsilon^{\text{class}}_{\text{accomp}}$ ($\epsilon^{\text{class}}_{\text{bdecay}}$).

For the second check the number of particles from b-hadron decays are calculated from the positive impact parameter alone and the result is used to calculate the fraction fulfilling $|\cos\alpha| < 0.975$. In both cases the agreement between data and simulation is good and the maximal deviation is taken as the systematic uncertainty.

Attention is given to the numbers of protons coming from long living hyperons such as Λ or Σ. The fraction of protons coming from hyperon decays in b decays has been changed by about 30% in the Monte Carlo to be in agreement with measurements of DELPHI [16] and OPAL [24]. The resulting change in the fraction of protons with positive impact parameter is found to be well covered

Composition of the systematic errors on f_{Λ_b}	
1. Systematic uncertainties from the analysis	
dE/dx	1.7%
b-tag	0.8%
Imp. par. and $cos\alpha$	0.8%
Extrapolation	0.6%
Reconstr. efficiency	0.5%
Total	2.2%
2. Systematic uncertainties from branching ratios	
BR(b-meson $\rightarrow$ pX)	1.0%
BR(b-baryon $\rightarrow$ pX)	1.2%
Total	1.6%

Table 8: *The different contributions to the two systematic errors on f_{Λ_b}. The quoted errors are absolute.*

by the systematic uncertainty derived previously. The fraction of tracks from b decays having a positive impact parameter depends on the lifetime of the parent b-hadron. Since one of the motivations of this measurement was to test the difference in lifetimes between b-baryons and b-mesons, the differences found in the impact parameter distribution between Monte Carlo samples with different b lifetimes are taken into account in the systematic uncertainties but are not found to be large.

Several other sources of systematic uncertainties are investigated: the b-tag efficiencies, the reconstruction efficiencies, the muon fraction fixed in the likelihood fit, the efficiency correction of particles from nuclear interactions and the extrapolation of the measured momentum spectra over the whole momentum range. The latter has been checked by using HERWIG 5.6, JETSET 7.3 and JETSET 7.4 for the extrapolation and the JETSET prediction has been compared to the momentum spectra of protons from $B^{\pm}, B^0$ decays as measured by ARGUS [25] and CLEO [26] and found to be in good agreement.

Most of the uncertainties discussed above are also present in the proton-lepton analysis and partly cancel in the ratio $(f_{\Lambda_b}\mathrm{BR(b\text{-}baryon} \rightarrow \mathrm{p}l\bar{\nu}X))/f_{\Lambda_b}$. Additional uncertainties are due to lepton identification and the simulation of the lepton p_T spectra [19, 22]. The impact of the fixed branching ratios ($b \rightarrow c\bar{c}s$ with semileptonic $\bar{c}$ decay and b-baryon $\rightarrow \tau\bar{\nu}\mathrm{p}X$) is small and variations of 50% lead to negligible effects. The modelling of the p_T lepton spectra of the background processes is found to be of minor importance compared to that of the spectrum of the signal leptons. The uncertainty was estimated from the divergence between different theoretical predictions for b-meson decay as described in e.g. [19]. In addition the rate of four body semileptonic b-baryon decays has been varied from 0% to 40% and the Λ_b polarization, as measured by ALEPH in [27], was considered.

Overview over the systematic uncertainties on BR(b-baryon $\to$ p$l\bar{\nu}X$)	
1. Systematic uncertainties from the analysis	
dE/dx	0.46%
b-tag	0.34%
Impact parameter	0.23%
p_T spectra	0.19%
lepton selection	0.10%
Extrapolation	0.15%
Reconstr. efficiency	0.11%
Total	0.68%
2. Systematic uncertainties from branching ratios	
BR(b-meson $\to$ pX)	0.45%
BR(b-baryon $\to$ pX)	0.55%
Total	0.71%

Table 9: *The different contributions to the two systematic uncertainties on BR(b-baryon $\to$ p$l\bar{\nu}X$). The errors are absolute.*

The systematic uncertainties on BR(b-baryon $\to$ p$l\bar{\nu}X$) are listed in table 9.

8 Conclusions

The momentum spectra and mean multiplicities have been measured for pions, kaons and protons in Z $\to$ b$\bar{\text{b}}$, Z $\to$ c$\bar{\text{c}}$ and Z $\to$ u$\bar{\text{u}}$, d$\bar{\text{d}}$, s$\bar{\text{s}}$ separately. In b events particles from b-hadron decay were distinguished from non-leading particles. The b-baryon fraction and the absolute semileptonic branching ratio BR(b-baryon $\to$ p$l\bar{\nu}$X) have been evaluated from proton production and correlated proton-lepton production in b-hadron decays. The b-baryon fraction was estimated from the overall number of protons from b decays and was found to be

$$f_{\Lambda_b} = (10.2 \pm 0.7_{\text{stat}} \pm 2.7_{\text{sys}})\% \ . \tag{21}$$

This result was used for the measurement of the absolute branching ratio of the decay b-baryon $\to$ p$l\bar{\nu}X$.

$$\text{BR(b-baryon} \to \text{p}l\bar{\nu}X) = (4.63 \pm 0.72_{\text{stat}} \pm 0.98_{\text{sys}})\% \ . \tag{22}$$

The ratio $R_{\text{p}l}$ =BR(b-baryon $\to$ p$l\bar{\nu}X$)/BR(b-baryon $\to$ pX) has been found to be

$$R_{\text{p}l} = 0.080 \pm 0.012_{\text{stat}} \pm 0.014_{\text{sys}} \ . \tag{23}$$

This relatively small number supports the small lifetime of b-baryons with respect to b-mesons as measured at LEP.

Acknowledgements

We wish to thank our colleagues from the accelerator divisions for the successful operation of the LEP machine, and the engineers and technical staff in all our institutions for their contribution to the good performance of ALEPH. Those of us from non-member states thank CERN for its hospitality.

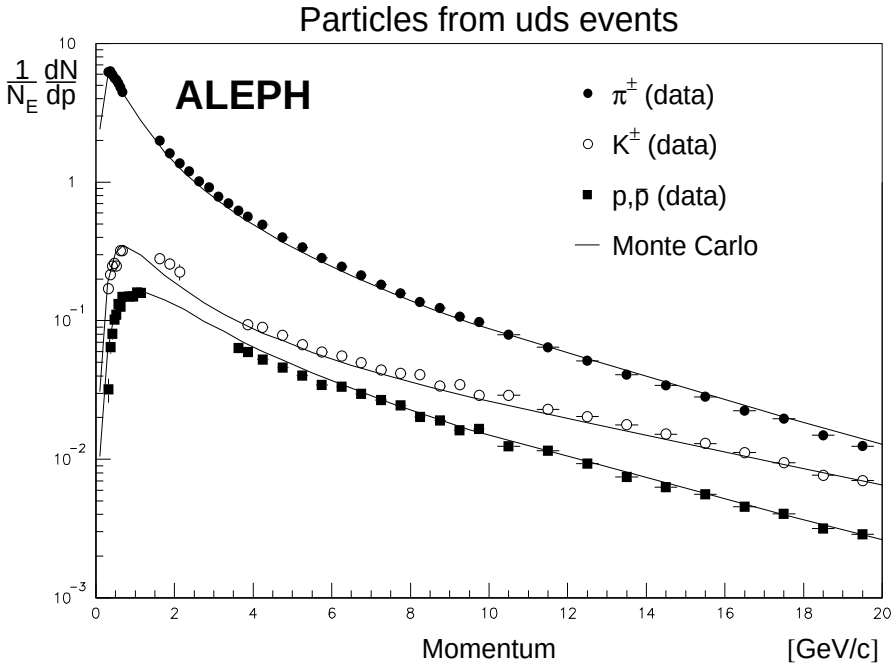

Figure 7: *Momentum spectra from pions, kaons and protons in uds events together with the Monte Carlo predictions. The errors shown are the quadratic sum of statistical and systematic errors.*

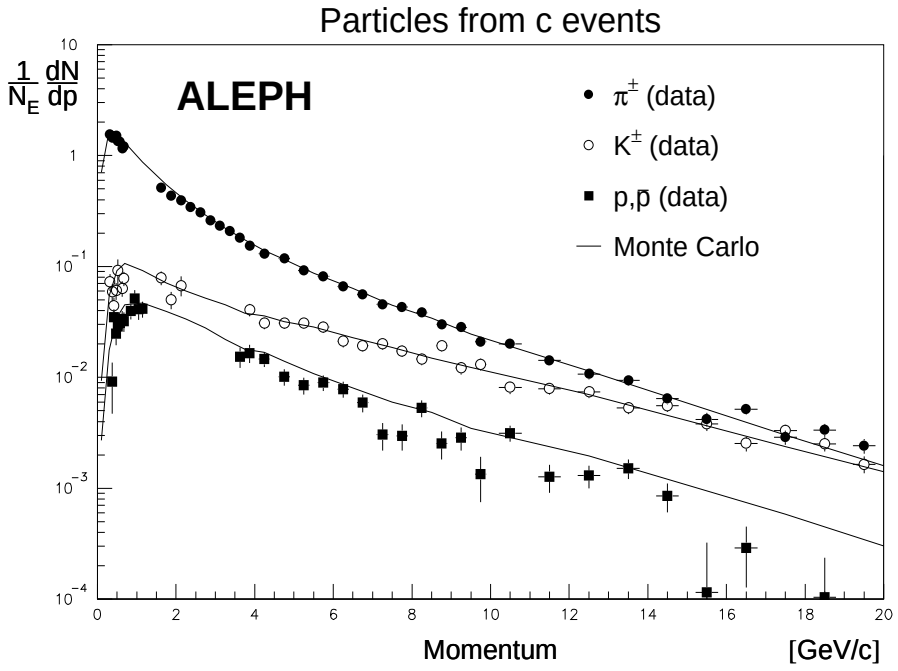

Figure 8: *Momentum spectra from pions, kaons and protons in c events together with the Monte Carlo predictions. The errors shown are the quadratic sum of statistical and systematic errors.*

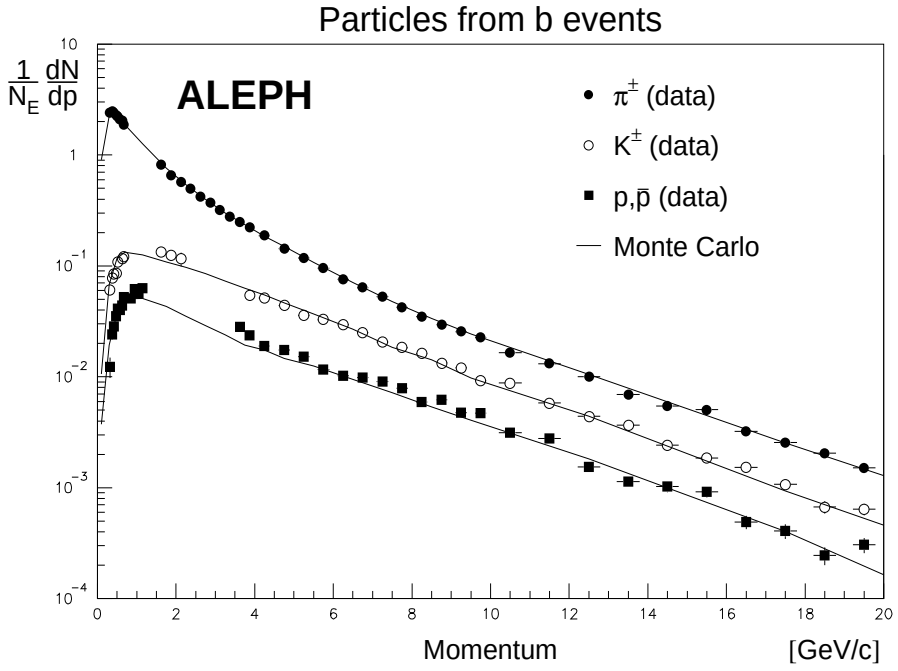

Figure 9: *Momentum spectra from pions, kaons and protons in b events together with the Monte Carlo predictions. The errors shown are the quadratic sum of statistical and systematic errors.*

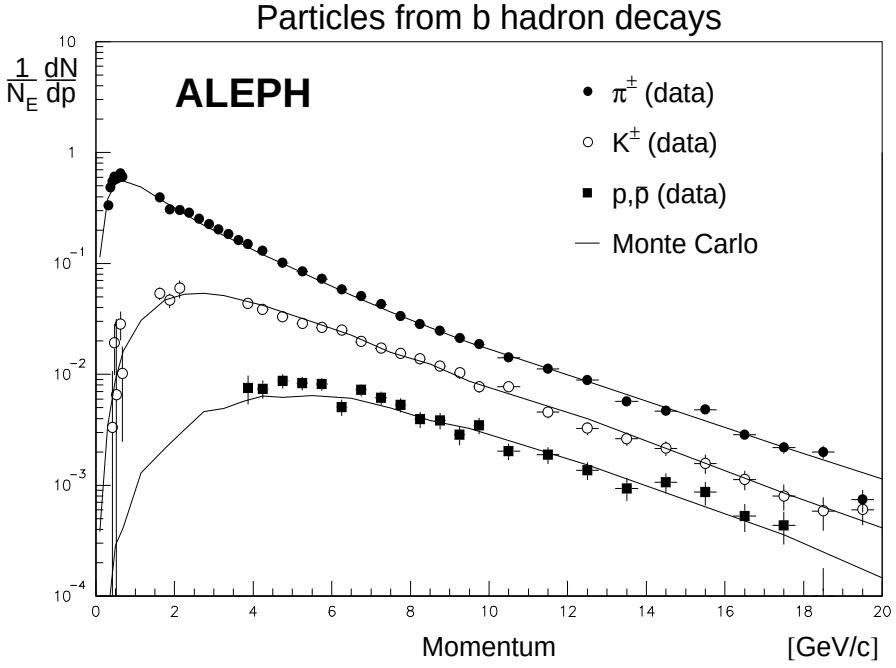

Figure 10: *Momentum spectra from pions, kaons and protons from b-hadron decays together with the Monte Carlo predictions. The errors shown are the quadratic sum of statistical and systematic errors.*

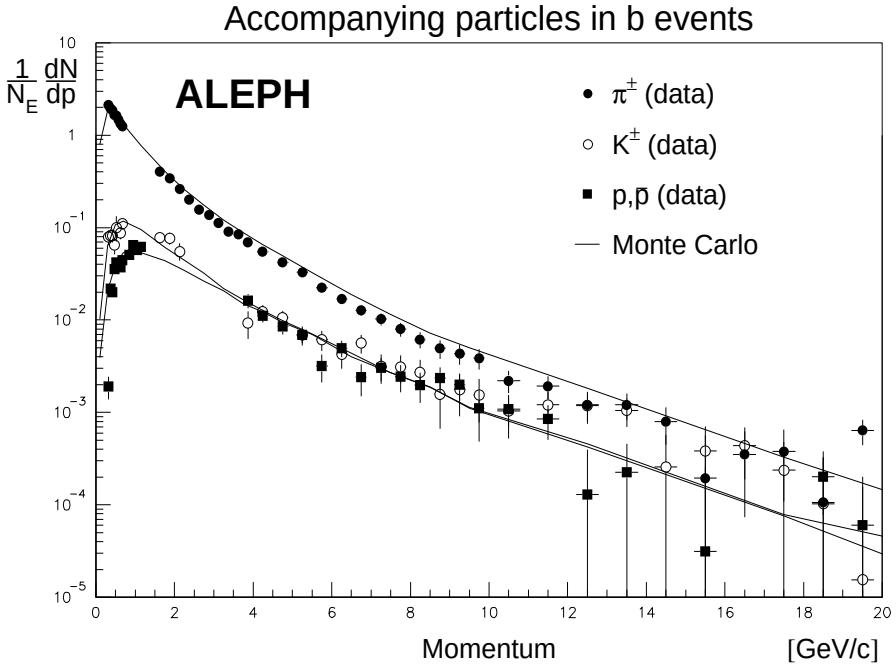

Figure 11: *Momentum spectra of pions, kaons and protons accompanying b-hadrons in b events together with the Monte Carlo predictions. The errors shown are the quadratic sum of statistical and systematic errors.*

Appendix

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	6.34	±	0.04	±	0.19
0.35	–	0.40	6.33	±	0.04	±	0.19
0.40	–	0.45	5.95	±	0.03	±	0.18
0.45	–	0.50	5.68	±	0.03	±	0.18
0.50	–	0.55	5.47	±	0.03	±	0.16
0.55	–	0.60	5.14	±	0.02	±	0.15
0.60	–	0.65	4.89	±	0.02	±	0.15
0.65	–	0.70	4.49	±	0.02	±	0.14
1.50	–	1.75	1.98	±	0.01	±	0.06
1.75	–	2.00	1.61	±	0.01	±	0.05
2.00	–	2.25	1.36	±	0.01	±	0.04
2.25	–	2.50	1.19	±	0.01	±	0.04
2.50	–	2.75	1.01	±	0.01	±	0.03
2.75	–	3.00	0.906	±	0.004	±	0.029
3.00	–	3.25	0.784	±	0.003	±	0.025
3.25	–	3.50	0.694	±	0.003	±	0.022
3.50	–	3.75	0.621	±	0.003	±	0.020
3.75	–	4.00	0.562	±	0.003	±	0.018
4.00	–	4.50	0.487	±	0.002	±	0.016
4.50	–	5.00	0.397	±	0.002	±	0.013
5.00	–	5.50	0.334	±	0.002	±	0.011
5.50	–	6.00	0.283	±	0.002	±	0.010
6.00	–	6.50	0.245	±	0.001	±	0.008
6.50	–	7.00	0.214	±	0.001	±	0.007
7.00	–	7.50	0.183	±	0.001	±	0.006
7.50	–	8.00	0.156	±	0.001	±	0.005
8.00	–	8.50	0.136	±	0.001	±	0.004
8.50	–	9.00	0.122	±	0.001	±	0.004
9.00	–	9.50	0.107	±	0.001	±	0.003
9.50	–	10.00	0.0975	±	0.0009	±	0.0031
10.00	–	11.00	0.0791	±	0.0006	±	0.0025
11.00	–	12.00	0.0644	±	0.0005	±	0.0021
12.00	–	13.00	0.0516	±	0.0004	±	0.0017
13.00	–	14.00	0.0407	±	0.0004	±	0.0013
14.00	–	15.00	0.0343	±	0.0004	±	0.0011
15.00	–	16.00	0.0283	±	0.0003	±	0.0009
16.00	–	17.00	0.0223	±	0.0003	±	0.0007
17.00	–	18.00	0.0197	±	0.0003	±	0.0006
18.00	–	19.00	0.0150	±	0.0002	±	0.0005
19.00	–	20.00	0.0123	±	0.0002	±	0.0004

Table 10: *Pions from uds events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E} \cdot \frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
.30	–	.35	$.170 \cdot 10^{+0}$	$\pm$	$.110 \cdot 10^{-1}$	$\pm$	$.594 \cdot 10^{-2}$
.35	–	.40	$.214 \cdot 10^{+0}$	$\pm$	$.890 \cdot 10^{-2}$	$\pm$	$.749 \cdot 10^{-2}$
.40	–	.45	$.250 \cdot 10^{+0}$	$\pm$	$.679 \cdot 10^{-2}$	$\pm$	$.874 \cdot 10^{-2}$
.45	–	.50	$.259 \cdot 10^{+0}$	$\pm$	$.738 \cdot 10^{-2}$	$\pm$	$.905 \cdot 10^{-2}$
.50	–	.55	$.249 \cdot 10^{+0}$	$\pm$	$.178 \cdot 10^{-1}$	$\pm$	$.871 \cdot 10^{-2}$
.60	–	.65	$.321 \cdot 10^{+0}$	$\pm$	$.706 \cdot 10^{-2}$	$\pm$	$.112 \cdot 10^{-1}$
.65	–	.70	$.321 \cdot 10^{+0}$	$\pm$	$.709 \cdot 10^{-2}$	$\pm$	$.112 \cdot 10^{-1}$
1.50	–	1.75	$.280 \cdot 10^{+0}$	$\pm$	$.461 \cdot 10^{-2}$	$\pm$	$.168 \cdot 10^{-1}$
1.75	–	2.00	$.256 \cdot 10^{+0}$	$\pm$	$.486 \cdot 10^{-2}$	$\pm$	$.154 \cdot 10^{-1}$
2.00	–	2.25	$.225 \cdot 10^{+0}$	$\pm$	$.675 \cdot 10^{-2}$	$\pm$	$.135 \cdot 10^{-1}$
3.75	–	4.00	$.938 \cdot 10^{-1}$	$\pm$	$.270 \cdot 10^{-2}$	$\pm$	$.563 \cdot 10^{-2}$
4.00	–	4.50	$.899 \cdot 10^{-1}$	$\pm$	$.161 \cdot 10^{-2}$	$\pm$	$.540 \cdot 10^{-2}$
4.50	–	5.00	$.782 \cdot 10^{-1}$	$\pm$	$.147 \cdot 10^{-2}$	$\pm$	$.469 \cdot 10^{-2}$
5.00	–	5.50	$.676 \cdot 10^{-1}$	$\pm$	$.140 \cdot 10^{-2}$	$\pm$	$.405 \cdot 10^{-2}$
5.50	–	6.00	$.592 \cdot 10^{-1}$	$\pm$	$.126 \cdot 10^{-2}$	$\pm$	$.355 \cdot 10^{-2}$
6.00	–	6.50	$.556 \cdot 10^{-1}$	$\pm$	$.140 \cdot 10^{-2}$	$\pm$	$.334 \cdot 10^{-2}$
6.50	–	7.00	$.499 \cdot 10^{-1}$	$\pm$	$.110 \cdot 10^{-2}$	$\pm$	$.300 \cdot 10^{-2}$
7.00	–	7.50	$.443 \cdot 10^{-1}$	$\pm$	$.104 \cdot 10^{-2}$	$\pm$	$.266 \cdot 10^{-2}$
7.50	–	8.00	$.417 \cdot 10^{-1}$	$\pm$	$.101 \cdot 10^{-2}$	$\pm$	$.250 \cdot 10^{-2}$
8.00	–	8.50	$.409 \cdot 10^{-1}$	$\pm$	$.957 \cdot 10^{-3}$	$\pm$	$.245 \cdot 10^{-2}$
8.50	–	9.00	$.336 \cdot 10^{-1}$	$\pm$	$.950 \cdot 10^{-3}$	$\pm$	$.202 \cdot 10^{-2}$
9.00	–	9.50	$.345 \cdot 10^{-1}$	$\pm$	$.883 \cdot 10^{-3}$	$\pm$	$.207 \cdot 10^{-2}$
9.50	–	10.00	$.290 \cdot 10^{-1}$	$\pm$	$.806 \cdot 10^{-3}$	$\pm$	$.174 \cdot 10^{-2}$
10.00	–	11.00	$.291 \cdot 10^{-1}$	$\pm$	$.546 \cdot 10^{-3}$	$\pm$	$.175 \cdot 10^{-2}$
11.00	–	12.00	$.228 \cdot 10^{-1}$	$\pm$	$.479 \cdot 10^{-3}$	$\pm$	$.137 \cdot 10^{-2}$
12.00	–	13.00	$.204 \cdot 10^{-1}$	$\pm$	$.443 \cdot 10^{-3}$	$\pm$	$.123 \cdot 10^{-2}$
13.00	–	14.00	$.177 \cdot 10^{-1}$	$\pm$	$.414 \cdot 10^{-3}$	$\pm$	$.106 \cdot 10^{-2}$
14.00	–	15.00	$.151 \cdot 10^{-1}$	$\pm$	$.396 \cdot 10^{-3}$	$\pm$	$.907 \cdot 10^{-3}$
15.00	–	16.00	$.130 \cdot 10^{-1}$	$\pm$	$.352 \cdot 10^{-3}$	$\pm$	$.777 \cdot 10^{-3}$
16.00	–	17.00	$.112 \cdot 10^{-1}$	$\pm$	$.295 \cdot 10^{-3}$	$\pm$	$.674 \cdot 10^{-3}$
17.00	–	18.00	$.946 \cdot 10^{-2}$	$\pm$	$.291 \cdot 10^{-3}$	$\pm$	$.568 \cdot 10^{-3}$
18.00	–	19.00	$.771 \cdot 10^{-2}$	$\pm$	$.268 \cdot 10^{-3}$	$\pm$	$.463 \cdot 10^{-3}$
19.00	–	20.00	$.704 \cdot 10^{-2}$	$\pm$	$.240 \cdot 10^{-3}$	$\pm$	$.422 \cdot 10^{-3}$

Table 11: *Kaons from uds events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.0319	±	0.0058	±	0.0010
0.35	–	0.40	0.0642	±	0.0045	±	0.0019
0.40	–	0.45	0.0806	±	0.0046	±	0.0024
0.45	–	0.50	0.102	±	0.004	±	0.003
0.50	–	0.55	0.110	±	0.004	±	0.003
0.55	–	0.60	0.131	±	0.004	±	0.004
0.60	–	0.65	0.127	±	0.004	±	0.004
0.65	–	0.70	0.148	±	0.004	±	0.004
0.80	–	0.90	0.149	±	0.003	±	0.004
0.90	–	1.00	0.150	±	0.006	±	0.004
1.00	–	1.10	0.159	±	0.006	±	0.005
1.10	–	1.20	0.158	±	0.004	±	0.005
3.50	–	3.75	0.0653	±	0.0025	±	0.0052
3.75	–	4.00	0.0595	±	0.0019	±	0.0048
4.00	–	4.50	0.0522	±	0.0011	±	0.0042
4.50	–	5.00	0.0461	±	0.0010	±	0.0037
5.00	–	5.50	0.0401	±	0.0009	±	0.0032
5.50	–	6.00	0.0345	±	0.0008	±	0.0028
6.00	–	6.50	0.0333	±	0.0008	±	0.0027
6.50	–	7.00	0.0297	±	0.0007	±	0.0024
7.00	–	7.50	0.0268	±	0.0006	±	0.0021
7.50	–	8.00	0.0245	±	0.0006	±	0.0020
8.00	–	8.50	0.0202	±	0.0006	±	0.0016
8.50	–	9.00	0.0190	±	0.0005	±	0.0015
9.00	–	9.50	0.0162	±	0.0005	±	0.0013
9.50	–	10.00	0.0166	±	0.0005	±	0.0013
10.00	–	11.00	0.0124	±	0.0003	±	0.0010
11.00	–	12.00	0.0115	±	0.0003	±	0.0009
12.00	–	13.00	0.00933	±	0.00026	±	0.00075
13.00	–	14.00	0.00746	±	0.00026	±	0.00060
14.00	–	15.00	0.00627	±	0.00024	±	0.00050
15.00	–	16.00	0.00561	±	0.00021	±	0.00045
16.00	–	17.00	0.00454	±	0.00017	±	0.00036
17.00	–	18.00	0.00404	±	0.00016	±	0.00032
18.00	–	19.00	0.00316	±	0.00014	±	0.00025
19.00	–	20.00	0.00287	±	0.00013	±	0.00023

Table 12: *Protons from uds events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	1.54	±	0.05	±	0.120
0.35	–	0.40	1.46	±	0.05	±	0.12
0.40	–	0.45	1.48	±	0.04	±	0.12
0.45	–	0.50	1.51	±	0.04	±	0.12
0.50	–	0.55	1.34	±	0.04	±	0.11
0.55	–	0.60	1.32	±	0.03	±	0.11
0.60	–	0.65	1.16	±	0.03	±	0.09
0.65	–	0.70	1.20	±	0.03	±	0.10
1.50	–	1.75	0.511	±	0.021	±	0.041
1.75	–	2.00	0.431	±	0.017	±	0.035
2.00	–	2.25	0.390	±	0.010	±	0.031
2.25	–	2.50	0.341	±	0.008	±	0.027
2.50	–	2.75	0.304	±	0.007	±	0.024
2.75	–	3.00	0.259	±	0.008	±	0.021
3.00	–	3.25	0.233	±	0.005	±	0.019
3.25	–	3.50	0.209	±	0.005	±	0.017
3.50	–	3.75	0.180	±	0.005	±	0.014
3.75	–	4.00	0.154	±	0.004	±	0.012
4.00	–	4.50	0.130	±	0.003	±	0.010
4.50	–	5.00	0.118	±	0.003	±	0.009
5.00	–	5.50	0.092	±	0.002	±	0.007
5.50	–	6.00	0.0816	±	0.0021	±	0.0065
6.00	–	6.50	0.0658	±	0.0019	±	0.0053
6.50	–	7.00	0.0555	±	0.0018	±	0.0044
7.00	–	7.50	0.0455	±	0.0016	±	0.0036
7.50	–	8.00	0.0430	±	0.0015	±	0.0034
8.00	–	8.50	0.0382	±	0.0014	±	0.0031
8.50	–	9.00	0.0300	±	0.0013	±	0.0024
9.00	–	9.50	0.0281	±	0.0012	±	0.0023
9.50	–	10.00	0.0209	±	0.0011	±	0.0017
10.00	–	11.00	0.0200	±	0.0007	±	0.0016
11.00	–	12.00	0.0143	±	0.0006	±	0.0011
12.00	–	13.00	0.0107	±	0.0005	±	0.0009
13.00	–	14.00	0.00941	±	0.00048	±	0.00075
14.00	–	15.00	0.00642	±	0.00044	±	0.00051
15.00	–	16.00	0.00419	±	0.00045	±	0.00034
16.00	–	17.00	0.00514	±	0.00036	±	0.00041
17.00	–	18.00	0.00289	±	0.00034	±	0.00023
18.00	–	19.00	0.00336	±	0.00034	±	0.00027
19.00	–	20.00	0.00242	±	0.00029	±	0.00019

Table 13: *Pions from c events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.0726	±	0.0103	±	0.0058
0.35	–	0.40	0.0588	±	0.0085	±	0.0047
0.40	–	0.45	0.0441	±	0.0070	±	0.0035
0.45	–	0.50	0.0603	±	0.0084	±	0.0048
0.50	–	0.55	0.0920	±	0.0223	±	0.0074
0.60	–	0.65	0.0636	±	0.0081	±	0.0051
0.65	–	0.70	0.0777	±	0.0083	±	0.0062
1.50	–	1.75	0.0790	±	0.0057	±	0.0095
1.75	–	2.00	0.0501	±	0.0061	±	0.0065
2.00	–	2.25	0.0674	±	0.0085	±	0.0108
3.75	–	4.00	0.0408	±	0.0032	±	0.0041
4.00	–	4.50	0.0309	±	0.0020	±	0.0031
4.50	–	5.00	0.0310	±	0.0018	±	0.0031
5.00	–	5.50	0.0309	±	0.0016	±	0.0031
5.50	–	6.00	0.0285	±	0.0015	±	0.0029
6.00	–	6.50	0.0212	±	0.0015	±	0.0021
6.50	–	7.00	0.0194	±	0.0013	±	0.0019
7.00	–	7.50	0.0201	±	0.0012	±	0.0020
7.50	–	8.00	0.0173	±	0.0011	±	0.0017
8.00	–	8.50	0.0146	±	0.0011	±	0.0015
8.50	–	9.00	0.0193	±	0.0011	±	0.0019
9.00	–	9.50	0.0121	±	0.0009	±	0.0012
9.50	–	10.00	0.0131	±	0.0009	±	0.0013
10.00	–	11.00	0.00808	±	0.00057	±	0.00081
11.00	–	12.00	0.00792	±	0.00050	±	0.00079
12.00	–	13.00	0.00736	±	0.00044	±	0.00074
13.00	–	14.00	0.00532	±	0.00041	±	0.00053
14.00	–	15.00	0.00554	±	0.00039	±	0.00055
15.00	–	16.00	0.00381	±	0.00036	±	0.00038
16.00	–	17.00	0.00252	±	0.00029	±	0.00025
17.00	–	18.00	0.00330	±	0.00028	±	0.00033
18.00	–	19.00	0.00251	±	0.00027	±	0.00025
19.00	–	20.00	0.00165	±	0.00023	±	0.00017

Table 14: *Kaons from c events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.00073	±	0.00530	±	0.00062
0.35	–	0.40	0.0092	±	0.0043	±	0.0007
0.40	–	0.45	0.0350	±	0.0047	±	0.0028
0.45	–	0.50	0.0247	±	0.0044	±	0.0020
0.50	–	0.55	0.0287	±	0.0047	±	0.0023
0.55	–	0.60	0.0308	±	0.0047	±	0.0025
0.60	–	0.65	0.0334	±	0.0048	±	0.0027
0.65	–	0.70	0.0321	±	0.0052	±	0.0026
0.80	–	0.90	0.0395	±	0.0040	±	0.0032
0.90	–	1.00	0.0513	±	0.0078	±	0.0041
1.00	–	1.10	0.0413	±	0.0069	±	0.0033
1.10	–	1.20	0.0414	±	0.0048	±	0.0033
3.50	–	3.75	0.0133	±	0.0032	±	0.0015
3.75	–	4.00	0.0165	±	0.0023	±	0.0018
4.00	–	4.50	0.0146	±	0.0014	±	0.0016
4.50	–	5.00	0.0101	±	0.0012	±	0.0011
5.00	–	5.50	0.00850	±	0.00107	±	0.00094
5.50	–	6.00	0.00896	±	0.00095	±	0.00099
6.00	–	6.50	0.00783	±	0.00091	±	0.00086
6.50	–	7.00	0.00593	±	0.00082	±	0.00065
7.00	–	7.50	0.00303	±	0.00076	±	0.00033
7.50	–	8.00	0.00297	±	0.00071	±	0.00033
8.00	–	8.50	0.00530	±	0.00066	±	0.00058
8.50	–	9.00	0.00254	±	0.00065	±	0.00028
9.00	–	9.50	0.00287	±	0.00058	±	0.00032
9.50	–	10.00	0.00134	±	0.00056	±	0.00015
10.00	–	11.00	0.00315	±	0.00035	±	0.00035
11.00	–	12.00	0.00127	±	0.00032	±	0.00014
12.00	–	13.00	0.00130	±	0.00026	±	0.00014
13.00	–	14.00	0.00152	±	0.00025	±	0.00017
14.00	–	15.00	0.000853	±	0.000227	±	0.000094
15.00	–	16.00	0.000116	±	0.000208	±	0.000013
16.00	–	17.00	0.000290	±	0.000159	±	0.000032
17.00	–	18.00	−.000016	±	0.000148	±	0.000002
18.00	–	19.00	0.000103	±	0.000131	±	0.000011
19.00	–	20.00	−.000170	±	0.000120	±	0.000019

Table 15: *Protons from c events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	2.41	±	0.02	±	0.07
0.35	–	0.40	2.46	±	0.02	±	0.08
0.40	–	0.45	2.42	±	0.02	±	0.08
0.45	–	0.50	2.29	±	0.01	±	0.07
0.50	–	0.55	2.22	±	0.01	±	0.07
0.55	–	0.60	2.09	±	0.01	±	0.06
0.60	–	0.65	2.03	±	0.01	±	0.06
0.65	–	0.70	1.87	±	0.01	±	0.06
1.50	–	1.75	0.817	±	0.008	±	0.029
1.75	–	2.00	0.657	±	0.007	±	0.024
2.00	–	2.25	0.573	±	0.004	±	0.021
2.25	–	2.50	0.492	±	0.003	±	0.018
2.50	–	2.75	0.415	±	0.003	±	0.015
2.75	–	3.00	0.372	±	0.003	±	0.013
3.00	–	3.25	0.317	±	0.002	±	0.011
3.25	–	3.50	0.277	±	0.002	±	0.010
3.50	–	3.75	0.248	±	0.002	±	0.009
3.75	–	4.00	0.220	±	0.002	±	0.008
4.00	–	4.50	0.186	±	0.001	±	0.007
4.50	–	5.00	0.144	±	0.001	±	0.005
5.00	–	5.50	0.118	±	0.001	±	0.004
5.50	–	6.00	0.0950	±	0.0008	±	0.0034
6.00	–	6.50	0.0757	±	0.0007	±	0.0027
6.50	–	7.00	0.0632	±	0.0006	±	0.0023
7.00	–	7.50	0.0530	±	0.0006	±	0.0019
7.50	–	8.00	0.0421	±	0.0005	±	0.0015
8.00	–	8.50	0.0349	±	0.0005	±	0.0013
8.50	–	9.00	0.0296	±	0.0004	±	0.0011
9.00	–	9.50	0.0256	±	0.0004	±	0.0009
9.50	–	10.00	0.0225	±	0.0004	±	0.0008
10.00	–	11.00	0.0164	±	0.0002	±	0.0006
11.00	–	12.00	0.0131	±	0.0002	±	0.0005
12.00	–	13.00	0.0100	±	0.0002	±	0.0004
13.00	–	14.00	0.00691	±	0.00015	±	0.00025
14.00	–	15.00	0.00547	±	0.00014	±	0.00020
15.00	–	16.00	0.00505	±	0.00018	±	0.00018
16.00	–	17.00	0.00321	±	0.00012	±	0.00012
17.00	–	18.00	0.00255	±	0.00013	±	0.00009
18.00	–	19.00	0.00205	±	0.00011	±	0.00007
19.00	–	20.00	0.00150	±	0.00011	±	0.00005

Table 16: *Pions from b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.0601	±	0.0035	±	0.0024
0.35	–	0.40	0.0772	±	0.0032	±	0.0031
0.40	–	0.45	0.0837	±	0.0027	±	0.0034
0.45	–	0.50	0.0855	±	0.0032	±	0.0034
0.50	–	0.55	0.108	±	0.008	±	0.004
0.60	–	0.65	0.116	±	0.003	±	0.005
0.65	–	0.70	0.120	±	0.003	±	0.005
1.50	–	1.75	0.133	±	0.002	±	0.009
1.75	–	2.00	0.123	±	0.002	±	0.011
2.00	–	2.25	0.115	±	0.003	±	0.016
3.75	–	4.00	0.0536	±	0.0012	±	0.0032
4.00	–	4.50	0.0513	±	0.0008	±	0.0031
4.50	–	5.00	0.0438	±	0.0007	±	0.0026
5.00	–	5.50	0.0360	±	0.0006	±	0.0022
5.50	–	6.00	0.0327	±	0.0006	±	0.0020
6.00	–	6.50	0.0296	±	0.0005	±	0.0018
6.50	–	7.00	0.0250	±	0.0005	±	0.0015
7.00	–	7.50	0.0206	±	0.0004	±	0.0012
7.50	–	8.00	0.0183	±	0.0004	±	0.0011
8.00	–	8.50	0.0162	±	0.0004	±	0.0010
8.50	–	9.00	0.0134	±	0.0004	±	0.0008
9.00	–	9.50	0.0121	±	0.0003	±	0.0007
9.50	–	10.00	0.00923	±	0.00030	±	0.00055
10.00	–	11.00	0.00883	±	0.00020	±	0.00053
11.00	–	12.00	0.00581	±	0.00017	±	0.00035
12.00	–	13.00	0.00440	±	0.00014	±	0.00026
13.00	–	14.00	0.00366	±	0.00013	±	0.00022
14.00	–	15.00	0.00242	±	0.00012	±	0.00015
15.00	–	16.00	0.00186	±	0.00012	±	0.00011
16.00	–	17.00	0.00153	±	0.00009	±	0.00009
17.00	–	18.00	0.00107	±	0.00009	±	0.00006
18.00	–	19.00	0.000671	±	0.000074	±	0.000040
19.00	–	20.00	0.000639	±	0.000065	±	0.000038

Table 17: *Kaons from b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.0123	±	0.0024	±	0.0005
0.35	–	0.40	0.0241	±	0.0017	±	0.0010
0.40	–	0.45	0.0284	±	0.0016	±	0.0011
0.45	–	0.50	0.0353	±	0.0017	±	0.0014
0.50	–	0.55	0.0413	±	0.0018	±	0.0017
0.55	–	0.60	0.0400	±	0.0017	±	0.0016
0.60	–	0.65	0.0438	±	0.0018	±	0.0018
0.65	–	0.70	0.0525	±	0.0020	±	0.0021
0.80	–	0.90	0.0511	±	0.0015	±	0.0020
0.90	–	1.00	0.0616	±	0.0030	±	0.0025
1.00	–	1.10	0.0565	±	0.0029	±	0.0023
1.10	–	1.20	0.0631	±	0.0018	±	0.0025
3.50	–	3.75	0.0290	±	0.0013	±	0.0026
3.75	–	4.00	0.0237	±	0.0009	±	0.0021
4.00	–	4.50	0.0189	±	0.0005	±	0.0017
4.50	–	5.00	0.0175	±	0.0005	±	0.0016
5.00	–	5.50	0.0152	±	0.0004	±	0.0014
5.50	–	6.00	0.0116	±	0.0004	±	0.0010
6.00	–	6.50	0.0102	±	0.0003	±	0.0010
6.50	–	7.00	0.00988	±	0.00031	±	0.00089
7.00	–	7.50	0.00903	±	0.00029	±	0.00081
7.50	–	8.00	0.00787	±	0.00027	±	0.00071
8.00	–	8.50	0.00591	±	0.00024	±	0.00053
8.50	–	9.00	0.00618	±	0.00024	±	0.00056
9.00	–	9.50	0.00476	±	0.00022	±	0.00043
9.50	–	10.00	0.00469	±	0.00021	±	0.00042
10.00	–	11.00	0.00313	±	0.00013	±	0.00028
11.00	–	12.00	0.00277	±	0.00012	±	0.00025
12.00	–	13.00	0.00154	±	0.00009	±	0.00014
13.00	–	14.00	0.00113	±	0.00007	±	0.00010
14.00	–	15.00	0.00102	±	0.00007	±	0.00009
15.00	–	16.00	0.000915	±	0.000073	±	0.000082
16.00	–	17.00	0.000490	±	0.000055	±	0.000044
17.00	–	18.00	0.000406	±	0.000053	±	0.000037
18.00	–	19.00	0.000245	±	0.000041	±	0.000022
19.00	–	20.00	0.000305	±	0.000041	±	0.000028

Table 18: *Protons from b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.330	±	0.017	±	0.017
0.35	–	0.40	0.482	±	0.014	±	0.024
0.40	–	0.45	0.548	±	0.013	±	0.027
0.45	–	0.50	0.605	±	0.013	±	0.030
0.50	–	0.55	0.580	±	0.012	±	0.029
0.55	–	0.60	0.601	±	0.012	±	0.030
0.60	–	0.65	0.651	±	0.012	±	0.033
0.65	–	0.70	0.604	±	0.012	±	0.030
1.50	–	1.75	0.393	±	0.009	±	0.020
1.75	–	2.00	0.307	±	0.009	±	0.015
2.00	–	2.25	0.302	±	0.006	±	0.015
2.25	–	2.50	0.285	±	0.005	±	0.014
2.50	–	2.75	0.253	±	0.005	±	0.013
2.75	–	3.00	0.227	±	0.004	±	0.011
3.00	–	3.25	0.202	±	0.003	±	0.010
3.25	–	3.50	0.183	±	0.003	±	0.009
3.50	–	3.75	0.163	±	0.003	±	0.008
3.75	–	4.00	0.149	±	0.003	±	0.007
4.00	–	4.50	0.129	±	0.002	±	0.006
4.50	–	5.00	0.101	±	0.002	±	0.005
5.00	–	5.50	0.0848	±	0.0016	±	0.0042
5.50	–	6.00	0.0722	±	0.0015	±	0.0036
6.00	–	6.50	0.0583	±	0.0013	±	0.0029
6.50	–	7.00	0.0502	±	0.0012	±	0.0025
7.00	–	7.50	0.0425	±	0.0012	±	0.0021
7.50	–	8.00	0.0336	±	0.0010	±	0.0017
8.00	–	8.50	0.0281	±	0.0010	±	0.0014
8.50	–	9.00	0.0245	±	0.0009	±	0.0012
9.00	–	9.50	0.0212	±	0.0009	±	0.0011
9.50	–	10.00	0.0186	±	0.0008	±	0.0009
10.00	–	11.00	0.0141	±	0.0005	±	0.0007
11.00	–	12.00	0.0112	±	0.0004	±	0.0006
12.00	–	13.00	0.00893	±	0.00039	±	0.00045
13.00	–	14.00	0.00573	±	0.00033	±	0.00029
14.00	–	15.00	0.00466	±	0.00030	±	0.00023
15.00	–	16.00	0.00478	±	0.00033	±	0.00024
16.00	–	17.00	0.00286	±	0.00024	±	0.00014
17.00	–	18.00	0.00219	±	0.00024	±	0.00011
18.00	–	19.00	0.00200	±	0.00025	±	0.00010
19.00	–	20.00	0.000739	±	0.000166	±	0.000037

Table 19: *Pions from b-hadron decays normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	$-.0174$	$\pm$	0.0092	$\pm$	0.0009
0.35	–	0.40	$-.00368$	$\pm$	0.0085	$\pm$	0.00065
0.40	–	0.45	0.00331	$\pm$	0.00735	$\pm$	0.00087
0.45	–	0.50	0.0191	$\pm$	0.0091	$\pm$	0.001
0.50	–	0.55	0.00656	$\pm$	0.02480	$\pm$	0.00033
0.60	–	0.65	0.0284	$\pm$	0.0078	$\pm$	0.0014
0.65	–	0.70	0.0101	$\pm$	0.0076	$\pm$	0.0005
1.50	–	1.75	0.0536	$\pm$	0.0044	$\pm$	0.0054
1.75	–	2.00	0.0466	$\pm$	0.0045	$\pm$	0.0051
2.00	–	2.25	0.0596	$\pm$	0.0061	$\pm$	0.0089
3.75	–	4.00	0.0436	$\pm$	0.0023	$\pm$	0.0035
4.00	–	4.50	0.0387	$\pm$	0.0014	$\pm$	0.0031
4.50	–	5.00	0.0330	$\pm$	0.0013	$\pm$	0.0026
5.00	–	5.50	0.0288	$\pm$	0.0012	$\pm$	0.0023
5.50	–	6.00	0.0263	$\pm$	0.0011	$\pm$	0.0021
6.00	–	6.50	0.0250	$\pm$	0.0010	$\pm$	0.0020
6.50	–	7.00	0.0196	$\pm$	0.0009	$\pm$	0.0016
7.00	–	7.50	0.0172	$\pm$	0.0009	$\pm$	0.0014
7.50	–	8.00	0.0154	$\pm$	0.0008	$\pm$	0.0012
8.00	–	8.50	0.0137	$\pm$	0.0008	$\pm$	0.0011
8.50	–	9.00	0.0118	$\pm$	0.0007	$\pm$	0.0009
9.00	–	9.50	0.0103	$\pm$	0.0007	$\pm$	0.0008
9.50	–	10.00	0.00774	$\pm$	0.00062	$\pm$	0.00062
10.00	–	11.00	0.00773	$\pm$	0.00041	$\pm$	0.00062
11.00	–	12.00	0.00457	$\pm$	0.00036	$\pm$	0.00037
12.00	–	13.00	0.00326	$\pm$	0.00031	$\pm$	0.00026
13.00	–	14.00	0.00263	$\pm$	0.00028	$\pm$	0.00021
14.00	–	15.00	0.00216	$\pm$	0.00027	$\pm$	0.00017
15.00	–	16.00	0.00157	$\pm$	0.00027	$\pm$	0.00013
16.00	–	17.00	0.00113	$\pm$	0.00021	$\pm$	0.00009
17.00	–	18.00	0.000801	$\pm$	0.000201	$\pm$	0.000064
18.00	–	19.00	0.000584	$\pm$	0.000188	$\pm$	0.000047
19.00	–	20.00	0.000601	$\pm$	0.000157	$\pm$	0.000048

Table 20: *Kaons from b-hadron decays normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
3.75	–	4.00	0.00754	±	0.00212	±	0.00060
4.00	–	4.50	0.00741	±	0.00126	±	0.00059
4.50	–	5.00	0.00874	±	0.00107	±	0.00070
5.00	–	5.50	0.00832	±	0.00095	±	0.00067
5.50	–	6.00	0.00818	±	0.00084	±	0.00066
6.00	–	6.50	0.00506	±	0.00076	±	0.00041
6.50	–	7.00	0.00727	±	0.00072	±	0.00058
7.00	–	7.50	0.00615	±	0.00067	±	0.00049
7.50	–	8.00	0.00531	±	0.00063	±	0.00043
8.00	–	8.50	0.00394	±	0.00057	±	0.00032
8.50	–	9.00	0.00384	±	0.00058	±	0.00031
9.00	–	9.50	0.00285	±	0.00052	±	0.00023
9.50	–	10.00	0.00347	±	0.00052	±	0.00028
10.00	–	11.00	0.00203	±	0.00031	±	0.00016
11.00	–	12.00	0.00189	±	0.00029	±	0.00015
12.00	–	13.00	0.00137	±	0.00023	±	0.00011
13.00	–	14.00	0.000938	±	0.00020	±	0.00008
14.00	–	15.00	0.00106	±	0.00020	±	0.00009
15.00	–	16.00	0.000868	±	0.000196	±	0.000069
16.00	–	17.00	0.000528	±	0.000145	±	0.000042
17.00	–	18.00	0.000434	±	0.000137	±	0.000035
18.00	–	19.00	0.000068	±	0.000112	±	0.000005
19.00	–	20.00	0.000113	±	0.000081	±	0.000009

Table 21: *Protons from b-hadron decays normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	2.12	±	0.03	±	0.11
0.35	–	0.40	1.97	±	0.02	±	0.10
0.40	–	0.45	1.86	±	0.02	±	0.10
0.45	–	0.50	1.67	±	0.02	±	0.08
0.50	–	0.55	1.63	±	0.02	±	0.08
0.55	–	0.60	1.47	±	0.02	±	0.07
0.60	–	0.65	1.35	±	0.02	±	0.07
0.65	–	0.70	1.24	±	0.02	±	0.06
1.50	–	1.75	0.405	±	0.014	±	0.020
1.75	–	2.00	0.346	±	0.012	±	0.017
2.00	–	2.25	0.263	±	0.008	±	0.013
2.25	–	2.50	0.201	±	0.006	±	0.010
2.50	–	2.75	0.157	±	0.006	±	0.008
2.75	–	3.00	0.137	±	0.005	±	0.007
3.00	–	3.25	0.112	±	0.004	±	0.006
3.25	–	3.50	0.0913	±	0.0041	±	0.0046
3.50	–	3.75	0.0841	±	0.0039	±	0.0042
3.75	–	4.00	0.0701	±	0.0036	±	0.0035
4.00	–	4.50	0.0550	±	0.0024	±	0.0028
4.50	–	5.00	0.0420	±	0.0022	±	0.0021
5.00	–	5.50	0.0330	±	0.0020	±	0.0017
5.50	–	6.00	0.0223	±	0.0018	±	0.0011
6.00	–	6.50	0.0169	±	0.0017	±	0.0008
6.50	–	7.00	0.0127	±	0.0015	±	0.0006
7.00	–	7.50	0.0102	±	0.0014	±	0.0005
7.50	–	8.00	0.00796	±	0.00128	±	0.00040
8.00	–	8.50	0.00613	±	0.00117	±	0.00031
8.50	–	9.00	0.00493	±	0.00109	±	0.00025
9.00	–	9.50	0.00434	±	0.00103	±	0.00022
9.50	–	10.00	0.00387	±	0.00096	±	0.00019
10.00	–	11.00	0.00222	±	0.00059	±	0.00011
11.00	–	12.00	0.00192	±	0.00053	±	0.00010
12.00	–	13.00	0.00121	±	0.00045	±	0.00006
13.00	–	14.00	0.00122	±	0.00038	±	0.00006
14.00	–	15.00	0.000793	±	0.000342	±	0.000040
15.00	–	16.00	0.000194	±	0.000372	±	0.000010
16.00	–	17.00	0.000349	±	0.000275	±	0.000017
17.00	–	18.00	0.000381	±	0.000271	±	0.000019
18.00	–	19.00	0.000106	±	0.000272	±	0.000005
19.00	–	20.00	0.000636	±	0.000191	±	0.000032

Table 22: *Accompanying pions in b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.0789	±	0.0113	±	0.0040
0.35	–	0.40	0.0823	±	0.0103	±	0.0041
0.40	–	0.45	0.0819	±	0.0087	±	0.0041
0.45	–	0.50	0.0643	±	0.0107	±	0.0032
0.50	–	0.55	0.101	±	0.029	±	0.005
0.60	–	0.65	0.0881	±	0.0094	±	0.0044
0.65	–	0.70	0.110	±	0.009	±	0.006
1.50	–	1.75	0.0784	±	0.0055	±	0.0086
1.75	–	2.00	0.0768	±	0.0057	±	0.0100
2.00	–	2.25	0.0555	±	0.0077	±	0.0089
3.75	–	4.00	0.00934	±	0.00291	±	0.00075
4.00	–	4.50	0.0122	±	0.0018	±	0.0010
4.50	–	5.00	0.0106	±	0.0016	±	0.0008
5.00	–	5.50	0.00690	±	0.00144	±	0.00055
5.50	–	6.00	0.00615	±	0.00134	±	0.00049
6.00	–	6.50	0.00429	±	0.00124	±	0.00034
6.50	–	7.00	0.00563	±	0.00114	±	0.00045
7.00	–	7.50	0.00315	±	0.00106	±	0.00025
7.50	–	8.00	0.00311	±	0.00099	±	0.00025
8.00	–	8.50	0.00273	±	0.00093	±	0.00022
8.50	–	9.00	0.00158	±	0.00090	±	0.00013
9.00	–	9.50	0.00176	±	0.00083	±	0.00014
9.50	–	10.00	0.00154	±	0.00074	±	0.00012
10.00	–	11.00	0.00104	±	0.00050	±	0.00008
11.00	–	12.00	0.00122	±	0.00043	±	0.00010
12.00	–	13.00	0.00119	±	0.00037	±	0.00010
13.00	–	14.00	0.00105	±	0.00034	±	0.00008
14.00	–	15.00	0.000256	±	0.000314	±	0.000020
15.00	–	16.00	0.000384	±	0.000314	±	0.000031
16.00	–	17.00	0.000438	±	0.000245	±	0.000035
17.00	–	18.00	0.000239	±	0.000239	±	0.000019
18.00	–	19.00	0.000103	±	0.000218	±	0.000008
19.00	–	20.00	0.000015	±	0.000187	±	0.000001

Table 23: *Accompanying kaons in b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

p interval [GeV/c]			$\frac{1}{N_E}\frac{dN}{dp}$		Δ_{stat}		Δ_{sys}
0.30	–	0.35	0.00190	±	0.00050	±	0.00010
0.35	–	0.40	0.0218	±	0.0011	±	0.0011
0.40	–	0.45	0.0200	±	0.0010	±	0.0010
0.45	–	0.50	0.0357	±	0.0013	±	0.0018
0.50	–	0.55	0.0421	±	0.0014	±	0.0021
0.55	–	0.60	0.0396	±	0.0013	±	0.0020
0.60	–	0.65	0.0371	±	0.0012	±	0.0019
0.65	–	0.70	0.0444	±	0.0014	±	0.0022
0.80	–	0.90	0.0509	±	0.0012	±	0.0025
0.90	–	1.00	0.0645	±	0.0025	±	0.0032
1.00	–	1.10	0.0574	±	0.0022	±	0.0029
1.10	–	1.20	0.0621	±	0.0014	±	0.0031
3.50	–	3.75	0.0206	±	0.0007	±	0.0016
3.75	–	4.00	0.0162	±	0.0026	±	0.0013
4.00	–	4.50	0.0112	±	0.0015	±	0.0009
4.50	–	5.00	0.00849	±	0.00131	±	0.00068
5.00	–	5.50	0.00690	±	0.00116	±	0.00055
5.50	–	6.00	0.00316	±	0.00103	±	0.00025
6.00	–	6.50	0.00495	±	0.00093	±	0.00040
6.50	–	7.00	0.00241	±	0.00089	±	0.00019
7.00	–	7.50	0.00303	±	0.00082	±	0.00024
7.50	–	8.00	0.00244	±	0.00077	±	0.00020
8.00	–	8.50	0.00198	±	0.00070	±	0.00016
8.50	–	9.00	0.00236	±	0.00070	±	0.00019
9.00	–	9.50	0.00200	±	0.00062	±	0.00016
9.50	–	10.00	0.00111	±	0.00062	±	0.00009
10.00	–	11.00	0.00108	±	0.00037	±	0.00009
11.00	–	12.00	0.000855	±	0.000344	±	0.000068
12.00	–	13.00	0.000130	±	0.000264	±	0.000010
13.00	–	14.00	0.000225	±	0.000233	±	0.000018
14.00	–	15.00	0.000042	±	0.000231	±	0.000003
15.00	–	16.00	0.000031	±	0.000222	±	0.000003
16.00	–	17.00	0.000041	±	0.000165	±	0.000003
17.00	–	18.00	0.000035	±	0.000153	±	0.000003
18.00	–	19.00	0.000203	±	0.000123	±	0.000016
19.00	–	20.00	0.000444	±	0.000092	±	0.000035

Table 24: *Accompanying protons in b events normalized to the total number of events N_E. The systematic uncertainties of different momentum bins in the overlap region are correlated.*

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