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Angular analysis of the decay $B^+ \to K^*(892)^+ \mu^+ \mu^-$ in proton-proton collisions at $\sqrt{s} = 8$ TeV

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Abstract: Angular distributions of the decay $B^+ \to K^*(892)^+ \mu^+ \mu^-$ are studied using events collected with the CMS detector in $\sqrt{s} = 8$ TeV proton-proton collisions at the LHC, corresponding to an integrated luminosity of $20.0\,\mathrm{fb}^{-1}$. The forward-backward asymmetry of the muons and the longitudinal polarization of the $K^*(892)^+$ meson are determined as a function of the square of the dimuon invariant mass. These are the first results from this exclusive decay mode and are in agreement with a standard model prediction.

Keywords: *B* physics, Hadron-Hadron scattering (experiments)

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JHEP04(2021)124

Contents

JHEP04(2021)124

1 Introduction

The decays of heavy-flavor hadrons can be used to probe high mass scales by searching for effects caused by unknown heavy particles that modify the standard model (SM) description of the decay. Flavor changing neutral current decays, such as those involving $\mathrm{b} \to \mathrm{s}\mu^+\mu^-$ transitions, are particularly promising as they are forbidden at tree level, and only occur via loop diagrams. The lack of a dominating tree-level process allows for a greater sensitivity to the effects of new particles. These effects can appear as differences in the overall decay rate or as modifications to the angular distributions of the decay products.

In this paper, an analysis of the $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$ decay is performed, where K^{*+} indicates the $\mathrm{K}^*(892)^+$ meson. Charge-conjugate states are implied throughout the paper. The theoretical description of this decay requires four independent kinematic variables, which are chosen by convention to be three angles plus the square of the dimuon invariant mass (q^2). Two angular distributions are used to measure two decay observables, the muon forward-backward asymmetry, A_{FB}, and the K^{*+} longitudinal polarization fraction, F_{L}, in bins of q^2. The data for this analysis were collected in proton-proton (pp) collisions at a center-of-mass energy of 8 TeV by the CMS detector at the CERN LHC, and correspond to an integrated luminosity of $20.0\,\mathrm{fb}^{-1}$ [1]. Previous measurements of A_{FB} and F_{L} have been made in the exclusive mode $\mathrm{B}^0 \to \mathrm{K}^*(892)^0\mu^+\mu^-$ [2–8] and in a combination of decays of the form $\mathrm{B} \to \mathrm{K}^*(892)\ell^+\ell^-$ [9–11], where ℓ refers to an electron or a muon and the combinations are of $\mathrm{K}^*(892)$ isospin states and/or lepton flavor states. The results are generally consistent with the SM predictions [12–22]. This paper reports the first measurement of A_{FB} and F_{L} in the exclusive decay $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$, with the K^{*+} meson reconstructed in the $\mathrm{K}^0_{\mathrm{S}}\pi^+$ decay mode and the $\mathrm{K}^0_{\mathrm{S}}$ meson identified from its decay to a pair of charged pions.

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. The silicon tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. During the LHC running period when the data used in this paper were recorded, the silicon tracker consisted of 1440 silicon pixel and 15 148 silicon strip detector modules. For non-isolated particles of $1 < p_T < 10$ GeV and $|\eta| < 1.4$, the track resolutions are typically 1.5% in p_T and 25–90 (45–150) μm in the transverse (longitudinal) impact parameter [23]. Muons with $|\eta| < 2.4$ are measured with gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in ref. [24]. Distances that are measured with respect to the beamline are in the transverse plane.

Events of interest are selected using a two-tiered trigger system [25]. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors. The second level, known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing.

3 Event selection

The events used in this analysis are selected by a trigger designed specifically for finding b hadron decays that include two muons. The trigger requires two oppositely charged muons, each with transverse momentum $p_T > 3.5$ GeV and $|\eta| < 2.2$. The two muons are fitted to a common vertex and retained if the fit χ^2 probability is greater than 10% and the vertex is displaced from the beamline by at least three times the uncertainty in the distance. The dimuon system is further required to have $p_T > 6.9$ GeV, invariant mass between 1 and 4.8 GeV, and a momentum vector whose angle α with respect to the vector between the beamline and the dimuon vertex satisfies $\cos\alpha > 0.9$.

The offline reconstruction of the signal decay $B^+ \to K^{*+}\mu^+\mu^-$ requires two oppositely charged muons and a K^{*+} meson, where the K^{*+} meson is reconstructed in the $K^0_S\pi^+$ decay mode, and the K^0_S meson is identified through its decay to $\pi^+\pi^-$. The trigger requirements are reapplied to the corresponding offline quantities and the offline muon candidates must pass the soft muon criteria [26] and correspond to the muons that satisfied the trigger requirements. The K^0_S meson candidates are reconstructed by fitting pairs of oppositely charged tracks to a common vertex and selected using standard selection criteria. In particular, the tracks must have at least 6 hits in the silicon tracker, a χ^2 per degree of freedom (dof) less than 5, pass at a distance from the beamline at least 2 times its uncertainty, and have the closest distance between their trajectories be less than 1 cm. In addition, the fitted vertex must have a $\chi^2/\text{dof} < 7$ and be located at a distance from the beamline that is at least 15 times the calculated uncertainty in the distance. The

JHEP04(2021)124

two-track invariant mass must be within 17.3 MeV (three times the average resolution) of the K^0_S meson mass [27] when the tracks are assigned the charged pion mass. To remove $\Lambda \rightarrow p\pi^-$ decays, the two-track combination is rejected if the invariant mass is in the range 1.11–1.125 GeV when the high and low momentum tracks are assigned the proton and charged pion mass, respectively. Each K^0_S candidate is combined with two oppositely charged muons and a non-muon track, assumed to be a pion, in a fit to a common vertex to form a B^+ meson candidate. The $K^0_S\pi^+$ invariant mass is required to be within 100 MeV of the world-average K^{*+} mass [27], and the invariant mass of the $K^0_S\pi^+\mu^+\mu^-$ system, m, must be in the range $4.76 < m < 5.8$ GeV.

The remaining selection criteria are obtained by maximizing $S/\sqrt{S+B}$ for different event shape variables. The number of signal events, S, is obtained from the simulation (normalized to the data) and the number of background events, B, is obtained from the $K^0_S\pi^+\mu^+\mu^-$ data sideband invariant mass regions 4.76–5.18 and 5.38–5.8 GeV. The K^0_S meson p_T must be greater than 1 GeV. The pion track from the K^{*+} decay must have $p_T > 0.4$ GeV and an impact parameter with respect to the beamline of at least 0.4 times the uncertainty in this parameter found from the vertex fit. The B^+ candidate vertex must have a fit χ^2 probability larger than 10% and a separation from the beamline of at least 12 times the calculated uncertainty in the separation. The angle α between the vector from the beamline to the vertex location and the B^+ candidate momentum vector (in the transverse plane) must satisfy $\cos\alpha > 0.9994$. In 0.3% of the events in which a candidate passes the selection criteria, a second candidate also passes the same criteria. In these cases, the candidate with the smaller vertex fit χ^2 value is chosen.

The decay modes $B^+ \rightarrow K^{*+}J/\psi$ and $B^+ \rightarrow K^{*+}\psi(2S)$, followed by the dimuon decays of charmonium states J/ψ and $\psi(2S)$, have the same final-state particles as the signal mode. As described in section 4, the analysis is performed in bins of q^2 that exclude candidates in the $B^+ \rightarrow K^{*+}J/\psi$ and $B^+ \rightarrow K^{*+}\psi(2S)$ regions, namely $8.68 < q^2 < 10.09\,\text{GeV}^2$ and $12.86 < q^2 < 14.18\,\text{GeV}^2$. However, since events from charmonium decay are produced quite copiously, a significant contribution can still appear in the signal q^2 regions. This primarily occurs through two effects: finite detector resolution resulting in a reconstructed dimuon mass different than the true value, and decays of the two charmonium states in which a low-energy photon is emitted in addition to the two muons. Two additional requirements are used to remove these contributions. First, candidates that satisfy either $m_{J/\psi} - 5\sigma_q < q < m_{J/\psi} + 3\sigma_q$ or $|q - m_{\psi(2S)}| < 3\sigma_q$ are removed, where $m_{J/\psi}$ and $m_{\psi(2S)}$ are the world-average J/ψ and $\psi(2S)$ masses [27], respectively, and σ_q is the calculated uncertainty in q for each candidate. The second requirement specifically targets the radiative background by using the fact that the missing low-energy photon will shift q and m from their nominal values by a similar amount. Thus, these events are suppressed by requiring $|(m - m_{B^+}) - (q - m_{J/\psi})| > 0.09$ GeV and $|(m - m_{B^+}) - (q - m_{\psi(2S)})| > 0.03$ GeV. When the $B^+ \rightarrow K^{*+}J/\psi$ decay mode is used as a control sample, the requirements in this paragraph are not applied.

The Monte Carlo (MC) samples corresponding to the signal and control channels are simulated using PYTHIA 6.426 [28], with the unstable particle decays modeled by EVTGEN [29]. The particles are then propagated through a detailed model of the CMS detector

JHEP04(2021)124

with GEANT4 [30]. The reconstruction and selection of the MC generated events follow the same algorithms as for the collision data. The number and spatial distribution of additional pp collision vertices in the same or nearby beam crossings in the data are simulated by weighting the MC samples to match the distributions found in data. The signal MC samples are used to estimate the efficiency, which includes the detector acceptance, the trigger efficiency, and the efficiency for reconstructing and selecting the signal candidates.

4 Angular analysis

The measurement of A_{FB} and F_{L} is performed in three q^2 regions: $1 < q^2 < 8.68\,\mathrm{GeV}^2$, $10.09 < q^2 < 12.86\,\mathrm{GeV}^2$, and $14.18 < q^2 < 19\,\mathrm{GeV}^2$. The angular distribution of the signal process, $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$, depends on three variables as shown in figure 1: θ_{K} (the angle in the K^{*+} meson rest frame between the momentum of the $\mathrm{K}^0_{\mathrm{S}}$ meson and the negative of the B^+ meson momentum), θ_ℓ (the angle in the dimuon rest frame between the momentum of the positively charged muon and the negative of the B^+ meson momentum), and ϕ (the angle in the B^+ meson rest frame between the plane containing the two muons and the plane containing the $\mathrm{K}^0_{\mathrm{S}}$ and π^+ mesons). Since the extracted angular observables A_{FB} and F_{L} do not depend on ϕ, this angle is integrated out. While the $\mathrm{K}^0_{\mathrm{S}}\pi^+$ invariant mass is required to be consistent with coming from a K^{*+} resonance decay, there can still be S-wave $\mathrm{K}^0_{\mathrm{S}}\pi^+$ contributions [19, 31–33]. This is parameterized by two terms: the S-wave fraction, F_S, and the interference amplitude, A_S, between S- and P-wave decays. The parameters A_{FB}, F_{L}, F_S, and A_S are functions of q^2. The differential decay rate of the signal decay $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$, as a function of the angular variables and q^2, can be written [19, 33] as:

$$
\begin{aligned}
\frac{1}{\Gamma}\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_{\mathrm{K}}\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}q^2} = \frac{9}{16}\bigg\{ & \frac{2}{3}\Big[F_S + 2A_S\cos\theta_{\mathrm{K}}\Big]\left(1-\cos^2\theta_\ell\right) \\
& + (1-F_S)\Big[2F_{\mathrm{L}}\cos^2\theta_{\mathrm{K}}\left(1-\cos^2\theta_\ell\right) \\
& + \frac{1}{2}(1-F_{\mathrm{L}})\left(1-\cos^2\theta_{\mathrm{K}}\right)\left(1+\cos^2\theta_\ell\right) \\
& + \frac{4}{3}A_{\mathrm{FB}}\left(1-\cos^2\theta_{\mathrm{K}}\right)\cos\theta_\ell\Big]\bigg\}.
\end{aligned}
\tag{4.1}
$$

For each q^2 bin, the observables A_{FB} and F_{L} are extracted by performing an unbinned extended maximum likelihood fit with three independent variables: m, $\cos\theta_{\mathrm{K}}$, and $\cos\theta_\ell$. The unnormalized probability density function (pdf) used to fit the data is:

$$
\begin{aligned}
\mathrm{pdf}(m,\cos\theta_{\mathrm{K}},\cos\theta_\ell) = {} & Y_S\,S^m(m)\,S^a(\cos\theta_{\mathrm{K}},\cos\theta_\ell)\,\epsilon(\cos\theta_{\mathrm{K}},\cos\theta_\ell) \\
& + Y_B\,B^m(m)\,B^{\theta_{\mathrm{K}}}(\cos\theta_{\mathrm{K}})\,B^{\theta_\ell}(\cos\theta_\ell).
\end{aligned}
\tag{4.2}
$$

The parameters Y_S and Y_B are the signal and background yields, respectively, and are free parameters in the fit. The signal mass shape, $S^m(m)$, is modeled by the sum of two Gaussian functions with a common mean, and the shape parameters are fixed to the values obtained from fitting simulated signal events. The mass shape of the background,

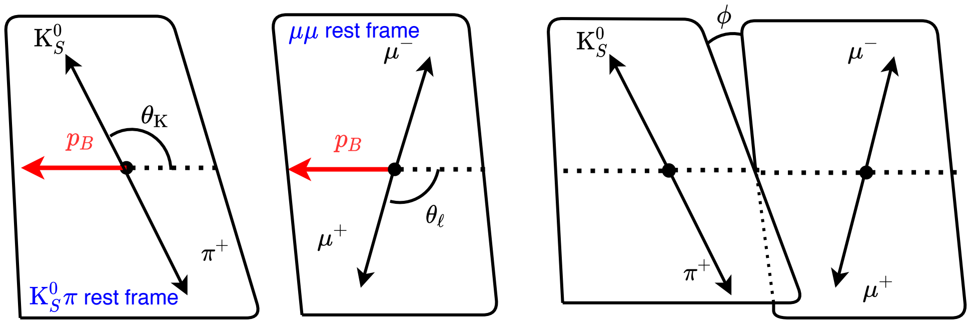

Figure 1. Definition of the angular observables θ_K (left), θ_ℓ (middle), and ϕ (right) for the decay $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$.

$B^m(m)$, is an exponential function with the exponent as a free parameter. The function $S^a(\cos\theta_\mathrm{K}, \cos\theta_\ell)$ is obtained from eq. (4.1) to describe the signal event distribution in the $(\cos\theta_\mathrm{K}, \cos\theta_\ell)$ angular space. Since the S-wave contribution is found to be small, F_S and A_S are fixed to zero in the nominal fit. The functions $B^{\theta_\mathrm{K}}(\cos\theta_\mathrm{K})$ and $B^{\theta_\ell}(\cos\theta_\ell)$ are the background shapes in the angular space. They are obtained by fitting the data events in the B^+ invariant mass sideband regions and fixed in the final fit. The $B^{\theta_\mathrm{K}}(\cos\theta_\mathrm{K})$ distributions are fitted to a sum of two exponential functions, a fourth-degree polynomial, and a third-degree polynomial for the low, middle, and high q^2 ranges, respectively. The $B^{\theta_\ell}(\cos\theta_\ell)$ distributions are fitted to a sum of two Gaussian functions, a fourth-degree polynomial, and a linear function for the low, middle, and high q^2 ranges, respectively.

The signal efficiency function in the two-dimensional angular spaces $\epsilon(\cos\theta_\mathrm{K}, \cos\theta_\ell)$ is obtained from the simulated samples using a two-step unbinned maximum likelihood fit process. In the first step, the efficiency in each q^2 bin is fitted to a product of two one-dimensional functions, one for each angular variable, assuming there is no correlation between the variables. The one-dimensional functions are polynomials of degree six, except for the $\cos\theta_\ell$ distribution of the first q^2 bin, which is a sum of three Gaussian functions. In the second step, a two-dimensional fit is performed on both angular variables, where the results from the first step are fixed, and an additional function is added to account for correlations. This function is the product of the powers 0, 1, 2, and 3 for Legendre polynomials with $\cos\theta_\mathrm{K}$ as the argument and the powers 0, 1, 3, and 4 for ordinary polynomials with $\cos\theta_\ell$ as the argument. This results in sixteen terms, each controlled by a free parameter in the fit. The signal efficiencies and the corresponding fits for each q^2 bin are shown as projections on $\cos\theta_\mathrm{K}$ (upper plots) and $\cos\theta_\ell$ (lower plots) in figure 2.

To test the fit, the reconstructed signal MC data set is split into 2000 random, disjoint samples, each with a similar number of signal events as the data sample. These are combined with background events generated using the appropriate pdf in eq. (4.2), with parameters taken from the fit to the data. Each sample is fitted in the same manner as the data and the resulting values for A_FB and F_L are found to have approximately Gaussian distributions with mean values close to the MC values. This indicates the fit is unbiased and accurate, even in the presence of background.

JHEP04(2021)124

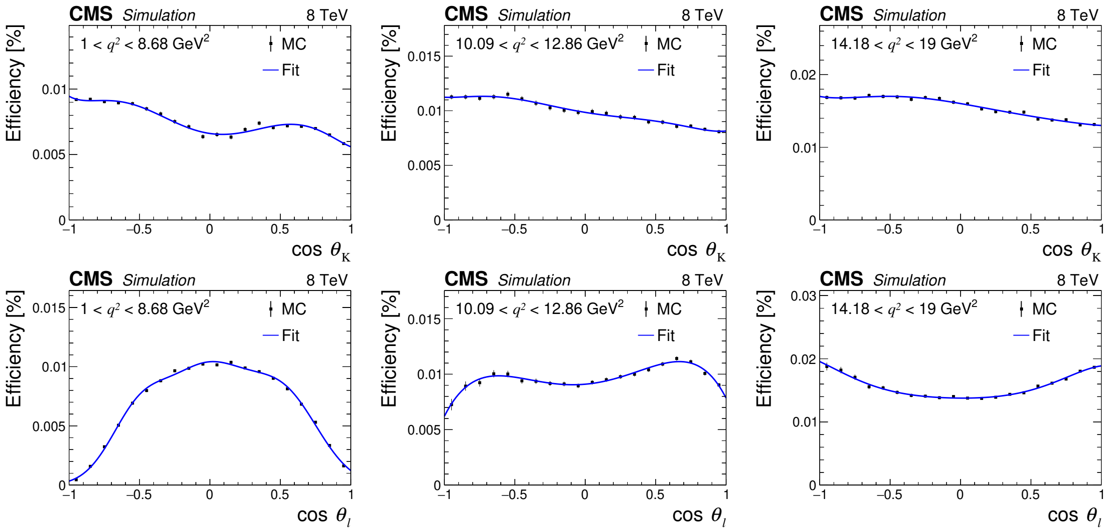

Figure 2. The signal efficiency as a function of $\cos\theta_{\mathrm{K}}$ (upper row) and $\cos\theta_{\ell}$ (lower row) from simulation for the q^2 ranges indicated. The vertical bars indicate the statistical uncertainty. The curves show the projection of the fitted result obtained from the two-dimensional fit, as described in the text.

The degree to which the simulation describes the data is examined by using the $\mathrm{B}^+ \to \mathrm{K}^{*+}\mathrm{J}/\psi$ MC sample to determine the efficiency, correcting the $\mathrm{B}^+ \to \mathrm{K}^{*+}\mathrm{J}/\psi$ data by this efficiency, and comparing the $\cos\theta_{\mathrm{K}}$ and $\cos\theta_{\ell}$ distributions with the SM expectations. The residual discrepancies are found to have a negligible effect on the measured values of A_{FB} and F_{L}.

5 Systematic uncertainties

Several sources of systematic uncertainties are considered in this analysis. First, the statistical uncertainty associated with the finite number of signal MC events is evaluated by generating 200 alternative efficiency functions, varying the function parameters according to their uncertainties. Each of these efficiency functions is used to fit the data, and the standard deviations of the distributions of the fitted values for A_{FB} and F_{L} are taken as the systematic uncertainty in each quantity. The second source of systematic uncertainty is from the shape used to parameterize the efficiency. The difference between the values of A_{FB} and F_{L} obtained from fitting the generator-level MC signal events (with no efficiency function) and the reconstructed MC signal events (with the efficiency function) is taken as the estimate for this systematic uncertainty.

The third systematic uncertainty arises from modeling the angular distribution of the background events and is composed of three components. The first component is intended to check the functional form. Instead of fitting the sideband data with the functional forms described in section 4, the lower and upper sidebands are individually fit to a non-parametric function and the two pdfs are combined according to their relative yields. The difference between the results obtained with this alternative background pdf and the default

Source	A_{FB} (10^{-3})	F_{L} (10^{-3})
MC statistical uncertainty	12–29	18–38
Efficiency model	3–25	4–12
Background shape functional form	0–9	0–33
Background shape statistical uncertainty	16–73	20–87
Background shape sideband region	28–153	38–78
S-wave contamination	4–22	5–12
Total systematic uncertainty	42–174	55–127

Table 1. Sources of systematic uncertainties and the effect on A_{FB} and F_{L}. The values given are absolute and the ranges indicate the variation over the q^2 bins.

function is taken as a systematic uncertainty. The second component is intended to account for the uncertainty regarding how well the background in the sideband regions represents the background in the signal region. In the nominal fit, large B^+ invariant mass sideband regions are used to determine the background shape in order to reduce the statistical uncertainty. As an alternate method, the background shape is determined from narrower sideband regions ($4.96 < m < 5.18\,\text{GeV}$ and $5.38 < m < 5.6\,\text{GeV}$), which are expected to be more representative of the signal region. Once the new background shape is determined, the fit is redone using all events (including the original sideband region), and the change in A_{FB} and F_{L} with respect to the nominal fit is used as the systematic uncertainty. Since the background shape parameters are fixed in the determination of A_{FB} and F_{L}, the third component accounts for the statistical uncertainty in the background shape. The data are fitted with 200 different background shapes obtained by varying the shape parameters by their uncertainties. The standard deviation of the distributions of the angular observables A_{FB} and F_{L} obtained from these 200 fits is included as a systematic uncertainty.

The fourth source of systematic uncertainty is the effect from S-wave contamination. The nominal fit does not include any S-wave contribution. We perform an alternative fit in which the S-wave fraction F_S is set to 5% and the S–P interference term A_S is a free parameter. The change in A_{FB} and F_{L} from the default fit is taken as the systematic uncertainty from S-wave contamination. Since the analysis of the similar decay mode $\mathrm{B}^0 \to \mathrm{K}^{*0}\mu^+\mu^-$ did not find F_S above 3% in any q^2 bin with many more signal events [5], an upper limit of 5% is a conservative choice.

The total systematic uncertainty is obtained by adding the individual contributions in quadrature for each q^2 bin. The systematic uncertainties, all considered to be symmetric, are summarized in table 1.

6 Results

Fits to the data are performed in three independent q^2 bins between 1 and $19\,\text{GeV}^2$. As described in section 4, the measured values for A_{FB} and F_{L} are obtained from an unbinned maximum likelihood fit in which both parameters are allowed to vary freely. The necessity of a nonnegative decay rate results in physical limits on A_{FB} and F_{L} that make it difficult

q^2 (GeV^2)	Y_S	A_{FB}	F_{L}
1–8.68	22.1 ± 8.1	$-0.14\,^{+0.32}_{-0.35} \pm 0.17$	$0.60\,^{+0.31}_{-0.25} \pm 0.13$
10.09–12.86	25.9 ± 6.3	$0.09\,^{+0.16}_{-0.11} \pm 0.04$	$0.88\,^{+0.10}_{-0.13} \pm 0.05$
14.18–19	45.1 ± 8.0	$0.33\,^{+0.11}_{-0.07} \pm 0.05$	$0.55\,^{+0.13}_{-0.10} \pm 0.06$

Table 2. The Y_S, A_{FB}, and F_{L} values from the fit for each q^2 range. The first uncertainty is statistical and the second is systematic.

JHEP04(2021)124

to determine the statistical uncertainties from the likelihood function. Therefore, the one dimensional uncertainty for A_{FB}, and separately for F_{L}, are evaluated using Neyman constructions following the method of Feldman-Cousins [34], generalized to treat nuisance parameters in the test statistic by the profile likelihood method. In the construction for A_{FB}, F_{L} is included in the nuisance parameters, and vice versa. In the Monte Carlo simulation of pseudo-experiments for obtaining the acceptance intervals in the construction, the nuisance parameters are treated by a parametric bootstrap procedure with profiling. That is, for each test value of the parameter of interest, the model including nuisance parameters is fit to the data to obtain the values of nuisance parameters that are used in the pseudo-experiments for constructing the acceptance intervals for that test value of the parameter of interest. The correlation coefficients between the two angular observables returned by MINUIT [35] are found to be 0.1 or less, depending on the q^2 bin. Tests with pseudo-experiments are used to verify that the statistical uncertainties have a coverage exceeding 68.3% in all cases.

The results of the unbinned maximum likelihood fit are overlaid on the data in projections of m (upper plots), $\cos\theta_{\mathrm{K}}$ (middle plots), and $\cos\theta_\ell$ (lower plots) for each q^2 region in figure 3. The fitted values of Y_S, A_{FB}, and F_{L}, along with their associated uncertainties, are given in table 2 for each of the q^2 bins. In order to more clearly observe the signal features, the data and fit results are shown versus the two angular variables in the invariant mass signal region $5.18 < m < 5.38\,\mathrm{GeV}$ in figure 4. The fitted values of A_{FB} and F_{L} are shown as a function of q^2 in figure 5, along with a SM prediction. This prediction combines quantum chromodynamic factorization and soft collinear effective theory at large recoil with heavy-quark effective theory and lattice gauge theory at small recoil to separate hard physics (around the b quark mass) from soft physics (around Λ_{QCD}) [20, 36–38]. While theoretical predictions are unavailable for the region between the J/ψ and $\psi(2\mathrm{S})$ meson masses ($10.09 < q^2 < 12.86\,\mathrm{GeV}^2$), the SM prediction agrees with the experimental results for the other q^2 bins, indicating no evidence of contributions from physics beyond the SM.

7 Summary

The first angular analysis of the exclusive decay $\mathrm{B}^+ \to \mathrm{K}^*(892)^+\mu^+\mu^-$, including the charge-conjugate state, has been performed using a sample of proton-proton collisions at

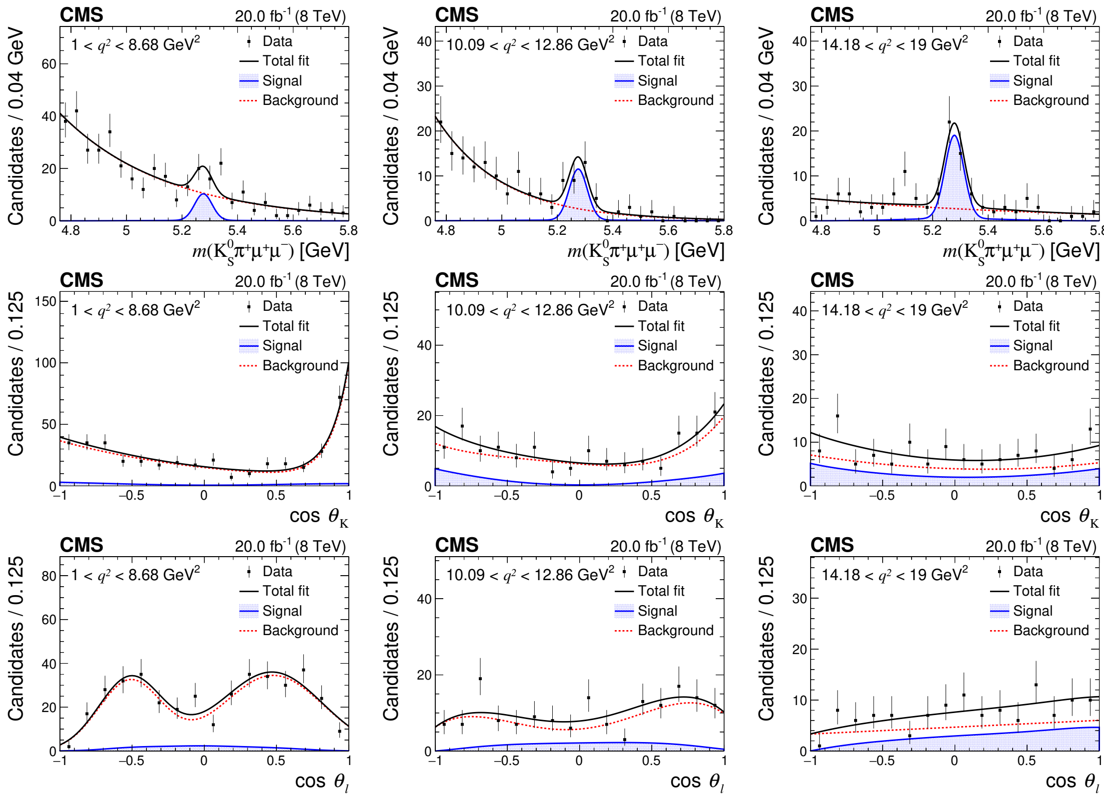

Figure 3. The $K^0_S\pi^+\mu^+\mu^-$ invariant mass (upper row), $\cos\theta_K$ (middle row), and $\cos\theta_\ell$ (lower row) distributions for each q^2 range is shown for data, along with the fit projections. The vertical bars on the data points indicate the statistical uncertainty. The filled areas, dashed lines, and solid lines represent the signal, background, and total contributions, respectively.

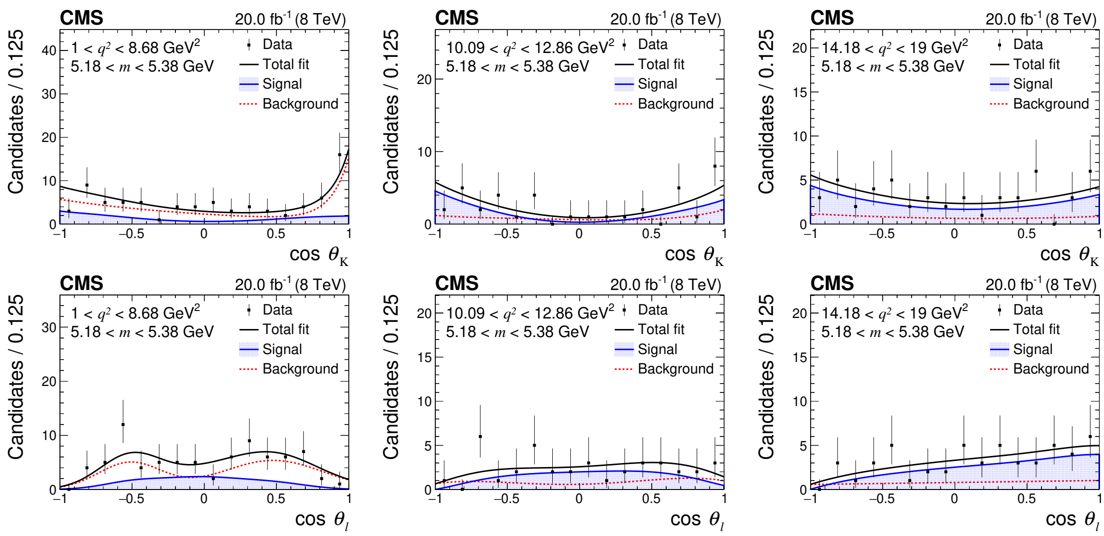

Figure 4. The $\cos\theta_K$ (upper row) and $\cos\theta_\ell$ (lower row) distributions for each q^2 range is shown for data in the invariant mass region $5.18 < m < 5.38$ GeV, along with the fit projections for the same region. The vertical bars on the data points indicate the statistical uncertainty. The filled areas, dashed lines, and solid lines represent the signal, background, and total contributions, respectively.

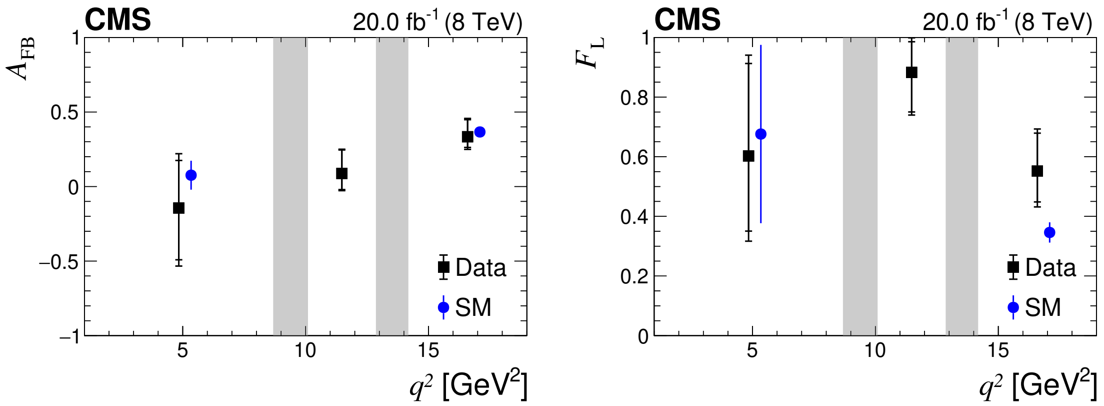

Figure 5. The measured values of A_{FB} (left) and F_{L} (right) versus q^2 for $\mathrm{B}^+ \to \mathrm{K}^{*+}\mu^+\mu^-$ decays are shown with filled squares, centered on the q^2 bin. The statistical (total) uncertainty is shown by inner (outer) vertical bars. The vertical shaded regions correspond to the regions dominated by $\mathrm{B}^+ \to \mathrm{K}^{*+}\mathrm{J}/\psi$ and $\mathrm{B}^+ \to \mathrm{K}^{*+}\psi(2\mathrm{S})$ decays. The SM predictions and associated uncertainties are shown by the filled circles and vertical bars, with the points slightly offset from the center of the q^2 bin for clarity.

a center-of-mass energy of 8 TeV. The data were collected with the CMS detector in 2012 at the LHC, and correspond to an integrated luminosity of 20.0 fb^{-1}. For each bin of the dimuon invariant mass squared (q^2), a three-dimensional unbinned maximum likelihood fit is performed on the distributions of the $\mathrm{K}^*(892)^+\mu^+\mu^-$ invariant mass and two decay angles. The muon forward-backward asymmetry, A_{FB}, and the $\mathrm{K}^*(892)^+$ longitudinal polarization fraction, F_{L}, are extracted from the fit in bins of q^2 and found to be consistent with a standard model prediction.

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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JHEP04(2021)124

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75: Also at Ozyegin University, Istanbul, Turkey
76: Also at Izmir Institute of Technology, Izmir, Turkey
77: Also at Necmettin Erbakan University, Konya, Turkey
78: Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey
79: Also at Marmara University, Istanbul, Turkey
80: Also at Milli Savunma University, Istanbul, Turkey
81: Also at Kafkas University, Kars, Turkey
82: Also at Istanbul Bilgi University, Istanbul, Turkey
83: Also at Hacettepe University, Ankara, Turkey
84: Also at Vrije Universiteit Brussel, Brussel, Belgium
85: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
86: Also at IPPP Durham University, Durham, United Kingdom
87: Also at Monash University, Faculty of Science, Clayton, Australia
88: Also at Bethel University, St. Paul, Minneapolis, U.S.A., St. Paul, U.S.A.
89: Also at Karamanoğlu Mehmetbey University, Karaman, Turkey

JHEP04(2021)124

90: Also at Bingol University, Bingol, Turkey
91: Also at Georgian Technical University, Tbilisi, Georgia
92: Also at Sinop University, Sinop, Turkey
93: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
94: Also at Erciyes University, KAYSERI, Turkey
95: Also at Texas A&M University at Qatar, Doha, Qatar
96: Also at Kyungpook National University, Daegu, Korea, Daegu, Korea