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Precise pion and kaon multiplicities at BELLE

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Summary. — Fragmentation functions (FFs) describe the formation of final state particles from a partonic initial state. Precise knowledge of these functions, especially spin-average FFs, is a key ingredient in accessing quantities such as the nucleon spin structure in semi-inclusive deep inelastic scattering and proton-proton collisions. However, fragmentation functions can currently not be determined from Quantum Chromodynamics first principles and have to be extracted from experimental data. The Belle experiment at KEK, Japan, provides a large data sample for high precision measurements of unpolarized and polarized fragmentation functions. Here, final extraction of the spin-independent FFs for identified pions and kaons will be presented.

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1. – Introduction

Fragmentation is the QCD process in which partons hadronize to colorless hadrons. Being a non-perturbative process, it is not possible to define it from first QCD principles, and it is generally parametrized in a number of fragmentation functions. Fragmentation functions are not only interesting as they shed light on parton hadronization and confinment, but are also needed for a complete description of the internal structure of the proton, QCD fundamental state. Indeed, proton structure is mainly accessed in semi-inclusive deep inelastic scattering or in proton-proton reactions. In both cases, the parton distribution functions, describing the non-perturbative distribution of partons in the proton, come in combination with fragmentation functions. Thus, the knowledge of fragmentation functions is a necessary input for a clean extraction of parton distributions.

The cleanest way to access fragmentation functions is via e^+e^- annihilation into hadrons, as for this reaction fragmentation is the only non-perturbative object in the cross section. Present knowledge of the spin-averaged fragmentation functions, object of this report, is dominated by the precise measurements by LEP experiments at CERN, at center-of-mass energies higher than 90 GeV, and, at lower energies, by PETRA experiments at DESY, although other measurements exists([1]). Several QCD analyses of these measurements have been performed so far, and recently unpolarized fragmentation functions have been extracted from experimental data via global analyses that included e^+e^- measurements together with proton-proton [1] and semi-inclusive DIS [2, 3] data. These studies, in particular [3], provided the extraction of somehow precise unpolarized fragmentation functions for quarks and gluons, but highlighted the need for additional precise measurements in two kinematic areas: (a) the high z-region, where z is the fractional energy of the final hadron with respect to the original fragmenting parton, and (b) at low center-of-mass energies.

The high statistics collected by the BELLE experiment [4] at the KEKB e^+e^- asymmetric collider [5], at a center-of-mass energy of $\sqrt{s} = 10.52\,\text{GeV}$, provides a optimal data sample for precise fragmentation measurements in the kinematic region so far less covered by experimental data.

2. – BELLE experiment

The BELLE experiment is located at the asymmetric e^+e^- collider KEKB (8 GeV e^- and 3.5 GeV e^+ beams), Japan. Belle is a large solid-angle magnetic spectrometer consisting of a silicon vertex detector (SVD), a central drift chamber (CDC), an array of aerogel Cherenkov counters (ACC), a time of flight detector (TOF), and an electromagnetic calorimeter (ECL), all located in a superconducting solenoid magnet (1.5 T). A K^0-Muon detector (KLM) consisting of a sandwich of resistive plate chambers is located around the solenoid.

3. – Precise multiplicities for pions and kaons at BELLE

Spin-averaged fragmentation functions can be accessed in $e^+e^- \to q\bar{q}$ reactions via the measure of hadron multiplicities:

$$M^h(z, Q^2) = \frac{1}{\sigma_{tot}} \frac{\mathrm{d}\sigma(e^+e^- \to hX)}{\mathrm{d}z}, \tag{1}$$

as multiplicities can be expressed in term of quark fragmentation functions ($D^h_{q,\bar{q}}$) at LO QCD, and in terms of quarks and gluon fragmentation functions ($D^h_{q,\bar{q},g}$) at NLO QCD [3]. Where, in eq. (1), h is the final observed hadron, X is the unmeasured hadronic final state, and σ_{tot} is the total $e^+e^- \to q\bar{q}$ cross section.

At BELLE, precise multiplicities have been extracted from a 68 fb^{-1} e^+e^-, annihilation data sample for identified pions and kaons as function of the hadron energy fraction z in the kinematic range $0.2 \leq z < 1.0$. The raw measured multiplicities have been corrected for a number of experimental sources of systematics, listed in the next sections. For a more detailed description of the analysis and the corrections applied see [6].

3˙1. *Particle identification correction.* – The measured multiplicities have been extracted for identified pions and kaons. Belle particle identification (PID) rely on the

([1]) For a full review see the Particle Data Group: `http://pdg.lbl.gov/2012/reviews/rpp2012-rev-frag-functions.pdf`

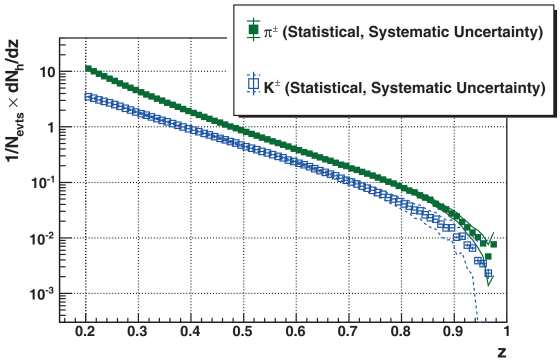

Fig. 1. – Charged-averaged pion and kaon multiplicities extracted at BELLE at a center-of-mass energy $\sqrt{s} = 10.52\,\text{GeV}$ [7].

combination of likelihoods for each track to be associated to an electron/positron, a muon, or a hadron (π, K, or p), provided by the CDC, the ACC, the ToF, the ECL and the KLM detectors. The global PID efficiencies for hadrons is very good, in particular it is about 90% for pions and about 85% for kaons. Nonetheless, in the context of a high precision measurements a $10-15\%$ misidentification level is not acceptable, so the PID for hadrons have been improved by using a data-driven unfolding procedure. In this procedure, PID probability matrices have been defined, that provide the probability for a track to be correctly identified/misidentified from the BELLE PID algorithm. Such matrices have been extracted by studying the decay of particles whose decay product species can be determined just from kinematic considerations: D^*, J/Ψ, Λ. For example in the decay of the D^*: $D^* \to \pi + D^0 \to \pi + (K\pi)$ the 2 pions have same sign, so it is straitforward to infer which tracks are pions and which is the kaon, and to study how the BELLE PID identify those tracks, and consequently extract a correction factor.

Detector performances, thus PID efficiencies, are momentum (p) and scattering angle dependent (θ), therefore PID probability matrices have been extracted in each of a $16(\theta)$ $\times 8$ (p) bins, and a 2D PID correction has been applied to multiplicities. The kinematic areas not covered by the decays under study have been corrected extrapolating the results from the measured kinematic area. The PID correction reach a 10% level in the pion sample and 20% in the kaon sample.

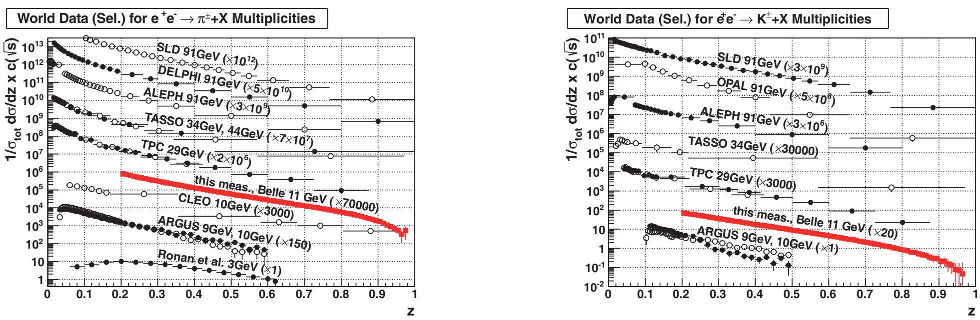

Fig. 2. – BELLE multiplicities for pions (left) and kaons (right) compared to a selection of existing measurements in a similar kinematic region.

3˙2. *Other corrections.* – Other corrections have also been applied to the raw multiplicities: hadron impurities from $\tau\tau$ and 2γ decays, detector smearing, hadrons lost because they decayed in flight, hadron interactions with detector materials, geometric and kinematic acceptance. In addition, multiplicities have been corrected for initial (ISR) and final (FSR) state radiation of a real photon. Indeed, the emission of a real photon changes the fragmentation energy scale, so that the BELLE data sample analyzed consists of events taken at nominal energy ($\sqrt{s} = 10.52\,\text{GeV}$) but also of events with slightly different energies. According to the DGLAP evolution, fragmentation functions are energy dependent, therefore the data sample should be corrected for possible events at different energies. The correction factor for ISR/FSR effects has been determined by analyzing 12 different MC tunes, eliminating events with more than a 0.5% change in energy.

3˙3. *Systematic uncertainties.* – The statistical and systematic uncertainties of the corrections mentioned in the previous section have been propagated and added in quadrature to give the final uncertainty of the multiplicities. In addition, a overall constant normalization uncertainty of 2.4% must be considered.

4. – Conclusions and outlook

Presently, the analysis has been finalized and final results for multiplicities are ready [7] and have been recently submitted to PRL. Final results for the corrected multiplicities for identified pions and kaons are shown in fig. 1. As shown in fig. 2, this new BELLE multiplicities provide very precise results compared to existing measurements, and cover the low center-of-mass energy and high z region poorly populated before. A preliminary version of this data has been already included in 2 global analyses, resulting in a significant reduction of theoretical uncertainty in the extraction of quark fragmentation functions [8, 9].

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