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Likelihood Methods for Beam Particle Identification at the COMPASS Experiment

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Abstract. COMPASS[2] is a multi-purpose fixed-target experiment at the CERN Super Proton Synchrotron (SPS) for investigating hadron structure as well as doing hadron spectroscopy. One main goal is the search for new hadronic states – in particular exotic mesons and glueballs – using hadron beams. The hadron beam provided for COMPASS consists of 97% pions, 2.4% kaons and a small fraction of antiprotons. Thus the identification of the incoming particle is an important ingredient to for all analyses. For the identification of beam particles two Čerenkov detectors of the CEDAR type are used. So far a simple multiplicity cut was used for the separation of pions and kaons. However, this method is not working properly for particles with an angle to the nominal beam direction. Thus a new method based on likelihoods has been developed and is presented here.

1 The COMPASS Experiment

The COMPASS (COmmon Muon and Proton Apparatus for Structure and Spectroscopy) experiment at CERN is a fixed-target experiment at the Super Proton Synchrotron (SPS) covering a broad spectrum of physics topics. The experimental setup consists of two magnetic spectrometers extending over a length of 50 m downstream of the target. These are the large angle spectrometer and the small angle spectrometer, respectively. In addition the trajectory of each incoming beam particle is measured in front of the target using a high resolution silicon detector telescope. Particle identification is performed using electromagnetic and hadron calorimeters as well as a ring imaging Čerenkov detector (RICH).

The main goal of the data taking in 2008 and 2009 was the investigation of the hadron spectrum with high intensity hadron beams. The data have been taken with a 190 GeV/c negative hadron beam impinging on a 40 cm liquid hydrogen target surrounded by a recoil proton detector. The beam consists mainly (97%) of pions but has also a contribution of 2.4% kaons and a small fraction of antiprotons. The method presented here only uses 2008 data but can be adapted also to 2009 data.

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2 The CEDAR detectors

The COMPASS experiment uses two Čerenkov detectors of the CEDAR type[1] for the identification of beam particles, i.e. the separation of pions and kaons. By adjusting the pressure of the filling gas and thus the refractive index the emitted light ring of the kaons is guided through a diaphragm and collected with 8 photomultipliers (cf. fig. 1). So far a cut on the multiplicity of the response of the photomultipliers was used to separate kaons from pions. If a certain number of photomultipliers (typically 6 of 8) show a signal the particle is identified as a kaon. This method only works if the particle to be identified traverses the detector parallel to the nominal beam axis. Otherwise the light rings are tilted out of the acceptance of the diaphragm. Particles with larger angles to the nominal beam axis have to be excluded from analyses. This results in a loss of information for about 50% of the events. Therefore a new method was developed which is also valid for particles with larger angles.

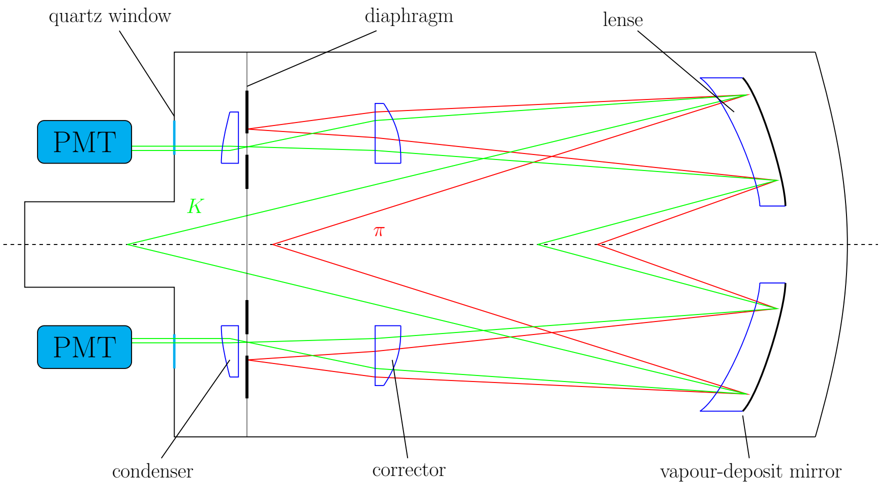


Fig. 1: Functional principle of a CEDAR detector: By choosing the correct refractive index one of the light rings is selected.

3 The Likelihood Method

The central idea of the new method is to use the response (signal or no signal) of each photomultiplier separately. Thus the response on kaons and pions has to be determined as a function of the beam angles θ_x and θ_y. For this calibration samples containing only beam kaons or beam pions are needed. These samples are extracted from the COMPASS data. For the preparation of a kaon sample the free kaon decay into three charged pions $K^- \to \pi^-\pi^+\pi^-$ is used, for the preparation of a pion sample the diffractive production of three charged pions on liquid hydrogen $\pi^- p \to \pi^-\pi^+\pi^- p$ is used.

Using these samples the probability for a kaon (pion) to produce a signal in one of the photomultipliers $P(\text{signal}|K[\pi])$ can be determined as

$$P(\text{signal}|K[\pi]) = \frac{\text{Number of signals in PMT}}{\text{Number of beam particles in kaon (pion) sample}}. \tag{1}$$

To identify a particle the probability that a signal is produced by a kaon (pion) is needed. This probability can be calculates using Bayes' theorem:

$$P_{(\theta_x,\theta_y)}(K[\pi]|\text{signal}) = \frac{P_{(\theta_x,\theta_y)}(\text{signal}|K[\pi]) \cdot P_{(\theta_x,\theta_y)}(K[\pi])}{P_{(\theta_x,\theta_y)}(\text{signal})} \tag{2}$$

The additional probabilities $P_{(\theta_x,\theta_y)}(\text{kaon(pion)})$ and $P_{(\theta_x,\theta_y)}(\text{signal})$ are the same for pions and kaons and can thus be dropped for any further calculation. This means that the only quantity needed for this method are the probabilities (1) for kaons and pions to produce a signal in the single photomultipliers.

Having determined all probabilities log likelihoods for pions and kaons can be calculated as

$$\log L(K[\pi]) = \sum P_{(\theta_x,\theta_y)}(\text{signal}|K[\pi]) + \sum \left[1 - P_{(\theta_x,\theta_y)}(\text{signal}|K[\pi])\right], \tag{3}$$

where the first sum only counts photomultipliers with a signal and the second sum only those without a signal.

These likelihoods are now used to identify the beam particles. Therefore likelihood ratios (i.e. differences of the log likelihood) are used:

- $\log L^K > \log L^\pi + A \Rightarrow \text{PID } K$
- $\log L^\pi > \log L^K + B \Rightarrow \text{PID } \pi$
- else no PID given

The likelihood differences A and B have to be chosen by means of purity and efficiency (cf. section 4).

4 Efficiency and Purity

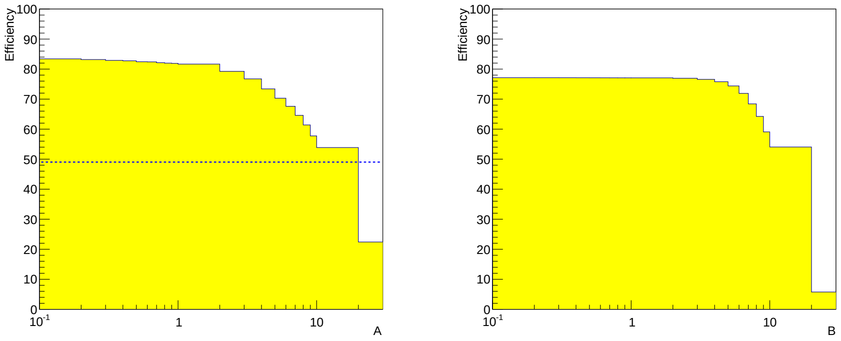
4.1 Efficiency

The COMPASS beam in the CEDAR region (30 m upstream of the target) is composed as follows:

$$\begin{aligned} \pi^- &: (96.77 \pm 4.33)\% \\ K^- &: (2.44 \pm 0.12)\% \\ \bar{p} &: (0.79 \pm 0.04)\% \end{aligned}$$

These values are now compared to the number of kaons and pions obtained using the likelihood method. Figure 2 shows the dependence of the efficiency on the likelihood differences A and B. As expected the number of identified particles drops with increasing differences.

For the identification of kaons also the value for the majority method is given (dotted line). Even for values of A up to 10 the efficiency of the likelihood method is still larger than the efficiency of the majority method. For the efficiency for pion identification no value for the majority method is given. As no positive pion identification is possible with the majority method the number of majority pions is just given by the number of "not kaons". Thus the obtained value for the efficiency would be larger than one and provides no information.



(a) Efficiency for kaons

(b) Efficiency for pions

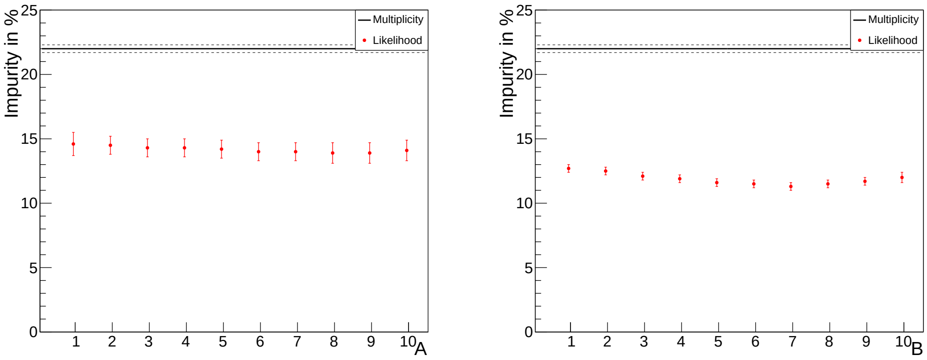
Fig. 2: Efficiencies for pion and kaon identification using the likelihood method. The dotted line indicates the value obtained by the multiplicity method.

4.2 Purity

For the calculation of purity the reaction

$$h^- p \to h'^- K^0_S p$$

is used. Due to conservation of strangeness the incoming hadron h^- can be tagged by identifying the outgoing hadron h'^- using the RICH. Therefore a cut on the particle momentum 8 GeV/$cp <$ 50 GeV/c is performed selecting the region where pions and kaons can be separated sufficiently well. Either pions or kaons are selected in the CEDARs. The number of “wrong” particles in the RICH can be used as a measure for the impurity of the CEDAR selection. The dependence on the likelihood differences A and B of the impurity for pions and kaons is shown in figure 3. The impurity does not depend strongly on the differences. Thus A and B can be chosen to obtain a large efficiency. The purity for kaons is comparable to the purity of the multiplicity method. The purity for pions is similar to the kaon purity. The value given for the majority method is not the true purity for pions as pions are only identified as “not kaons”. Thus also antiprotons and not identified kaons are in there. Nevertheless it is a value that can be compared to the new method. Using the likelihood method the purity is about about 40% better than using the multiplicity method.



(a) Impurity for kaons

(b) Impurity for pions

Fig. 3: Impurities for pion and kaon identification using the likelihood method. The balck lines indicate the value and error obtained from the multiplicity method.

5 Summary

It was shown that the newly developed likelihood method can improve the kaon identification in the CEDARs. The kaon identification efficiency is improved by ≈ 60% with a purity that is comparable with the multiplicity method. In addition the likelihood method allows to positively identify pions with a similar efficiency and purity. In table 1 all obtained values for efficiency and purity are summarized. As it is not possible to identify pions using the multiplicity method no value for the efficiency can be given.

	Likelihood	Multiplicity
kaon efficiency	$(80.3 \pm 0.4)\%$	$(48.4 \pm 0.2)\%$
kaon purity	$(85.4 \pm 0.9)\%$	$(86.9 \pm 0.9)\%$
pion efficiency	$(77.1 \pm 0.3)\%$	X
pion purity	$(87.5 \pm 0.3)\%$	$(78.0 \pm 0.3)\%$

Table 1: Efficiencies and purities for the likelihood method ($A = B = 1$, cut200) in comparison with the multiplicity method. Only statistical errors are given.

References

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