The Compact Muon Solenoid Experiment

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Particle identification with ionization energy loss in the CMS Silicon Strip Tracker

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Abstract

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Particle identification with ionization energy loss in the CMS silicon strip tracker

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The large sensitive volume of the Silicon Strip Tracker of the CMS detector allows up to 20 samplings of ionization energy loss for a typical track, providing a powerful tool for particle identification in the $0.2 < \beta < 0.9$ regime. We report on the application to hadron identification with the pp collisions recorded by CMS during the 2009-2010 run at $\sqrt{s} = 0.9$ and 7 TeV, on the validation of the method with constrained decays of known resonances, and on the future prospects for searches of highly-ionizing exotic particles.

1. Introduction

The mean ionization energy loss of a particle crossing a layer of material is given by the Bethe-Bloch formula [1]. It describes the mean rate of energy loss in the region $0.1 \leq \beta\gamma \leq 1000$ for intermediate-Z materials with an accuracy of a few percents, see figure 1. For thin layer of material ($\sim 500\mu m$), the Landau-Vavilov-Bichsel function [2] is a better parameterization of the ionization energy loss, but for non-relativistic particles, the two parameterizations are almost identical.

The mean energy loss can be used for particle identification since, for a given momentum and absorber material, it only depends on the mass of the incident particle. Particle identification is therefore possible in the region, $0.2 \leq \beta\gamma \leq 0.9$, where large differences in the energy loss are observed for small variations of the incident particle momentum. For higher values of $\beta\gamma$, the Bethe-Bloch function reaches a plateau where discrimination between particles is difficult. These constraints allow identification of low momenta hadrons (pions, kaons, protons and deuterons) in the CMS detector, but also of highly-ionizing exotic particles [3]. These particles predicted by

many models beyond the standard model are, given their high mass, generally non-relativistic particles at the LHC. In the restricted region of $\beta\gamma$ where identification is possible, the Bethe-Bloch formula can be linearized around m^2/p^2 with a few percent agreement with respect to the complete parameterizations.

$$\left\langle \frac{dE}{dx} \right\rangle = K \frac{m^2}{p^2} + C \quad (1)$$

A particle produced in CMS crosses in average 20 silicon modules before reaching the calorimeters. Each crossing point is a measurement of the particle specific ionization energy loss ($\Delta E/\Delta x$), it is simply computed as the hit cluster charge per unit of path-length in the silicon. The particle mean ionization energy loss needs to be estimated out of the ~ 20 measurements associated to the track. In order to combine all the measurements together, the 15148 modules composing the silicon strip tracker are inter-calibrated. By nature of the particle energy loss fluctuation in thin layer of material, each $\Delta E/\Delta x$ is strongly fluctuating and the mean energy loss is therefore generally not reliable enough to be used for particle identification. The most probable (MP) energy loss is more stable than the mean. For this reason, particle identification algorithms are generally using the most probable energy loss rather than the

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mean energy loss.

2. dE/dx estimators

The main purpose of the dE/dx estimators is to combine the many $\Delta E/\Delta x$ measurements distributed along the particle trajectory into one unique value: an estimation of the most probable energy loss of the track. The short-hand notation dE/dx is used for this estimation. The combination of the measurements is used to get rid of the large fluctuation of the individual $\Delta E/\Delta x$ measurements. Different estimators are used in CMS, but the favorite one is the Harmonic-2 estimator [4]. In the following equation, $k = -2$ and the N energy loss measurements are indexed by the variable i :

$$I_h^{Harmonic2} = \left(\frac{1}{N} \sum_{i=1}^N (\Delta E/\Delta x)_i^k \right)^{1/k} \quad (2)$$

The distribution of dE/dx versus momentum for high quality tracks with vertex compatibility is shown on figure 2 for 7 TeV collision events. The different visible bands are, from low to high momentum value, due to kaons, protons and deuterons.

3. Mass reconstruction

The parameterization described in (1) can be reversed to compute the mass of any non relativistic particle from its dE/dx and momentum. This requires nevertheless the knowledge of the K and C constants used in the parameterization. These can be extracted from the data themselves, using for instance tracks falling into the identified protons band. An other possible technique (not used here) is to select protons from Λ decays. Injecting the proton mass in the equation (1), the constants have been measured to be $K = 2.545$ and $C = 2.642$ for the observed data [5]. Three mass lines from the parameterization, assuming kaon, proton and deuteron mass, are also visible on figure 2. The red line segment shows the part of the proton band that were used to extract the constants.

The dE/dx -reconstructed mass spectrum using good quality tracks compatible with the event

vertex which have a $p < 2$ GeV and a $dE/dx > 5$ MeV/cm is visible on figure 2. A nice agreement is observed between data and simulation for the proton and the kaon peaks. The absence of the deuteron peak in the simulation appears because PYTHIA does not generate this particle.

4. Validation with Λ decay

A validation of the particle identification tool was performed with data collected with the CMS detector during LHC commissioning in December 2009 at a center-of-mass energy of 900 GeV [5]. The validation relies on the identification of protons from Λ decay into πp . The proton is always the hardest track of the Λ decay when $p_\Lambda > 0.3$ GeV. The figure 1 shows the dE/dx vs p plane for protons identified in this way, almost all of them are well distributed on the proton mass band. The few outliers are compatible with the expected background of the Λ spectrum.

5. Conclusion

The CMS particle identification algorithm based on dE/dx allows an unambiguous observation of the kaon, proton and deuterons in $\sqrt{s} = 0.9$ and 7 TeV data taken in 2009-2010. A validation of the algorithm was also performed with Λ decay. dE/dx tools are therefore ready for new physics searches, like the search for Heavy Stable Charged Particles [3].

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Figure 1. Top: Mean energy loss rate for different absorbers [1]. Bottom: Distribution of dE/dx versus p for hardest track of identified Λ decay [5].

Figure 2. Top: Distribution of dE/dx versus p for good quality tracks with vertex compatibility coming from 7 TeV collisions events. Bottom: Reconstructed mass of low momenta hadrons with $p < 2$ GeV and $dE/dx > 5.0$ MeV/cm. The peaks correspond, from lower to higher masses, to kaon, proton and deuteron invariant mass.