

Physics potential of timing layers for future detectors

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Abstract

Keywords:

1. Introduction

Future experiments, such as CLIC [1], International Linear Collider (ILC) [2], high-energy LHC (HE-LHC), future circular pp colliders of the European initiative, FCC-hh [3] and the Chinese initiative, SppC [4] will require high precision measurements of particle and jets at large transverse momenta. The usage of timing information for such experiments can provide additional information that can be used to improve particle and jet reconstruction, as well as to deal with background events. At this moment, conceptional design reports for these experiments did not fully explore the benefits of the time of flight (TOF) measurements with tens-of-picosecond resolutions.

2. Proposal

A generic design of hadronic (electromagnetic) calorimeters for future particle collision experiments (HE-LHC, FCC, CLIC, ILC etc.) is based on two main characteristics: (1) high-granularity calorimeters with cells ranged from $3 \times 3 \text{ mm}^2$ (for ECAL) to $5 \times 5 \text{ cm}^2$ (for HCAL) in sizes. (2) timing with nanosecond precision that improves background rejection, vertex association, and detection of new particles. According to the CPAD report [5], a development of picosecond time resolution for future calorimeters is one of the critical needs. Presently, high-granularity calorimeters (with ~ 1 millions channels) with tens of picoseconds resolution represent a significant challenge due the large cost.

As a part of the HL-LHC upgrade program, CMS and ATLAS experiments are designing high-precision timing detectors with the time resolution of about 30 ps. They are based on silicon sensors that add an extra “dimension to event reconstruction. Such timing capabilities are not fully explored for future detectors beyond the HL-LHC

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upgrade. High-precision timing will be beneficial for new physics searches and b-tagging for all post-LHC experiments. For CLIC and FCC, high-precision time stamping will be essential for background rejection and pile-up mitigation.

Currently, the baseline designs of the high-granularity ECAL and HCAL of the CLIC/FCC detectors have not been optimized for precision timing in the range of a few tens of picoseconds. The latter is considered as an expensive option for many millions of channels of these high-granularity detectors. This opens an opportunity to investigate a cost-effective timing layer (with the time resolution of smaller than 30 ps) for the post-LHC detectors. This layer will be installed on front of high-granularity calorimeters, covering both the forward and barrel regions.

In this paper we will investigate physics advantages for timing layers in the front of calorimeters of the post-LHC experiments. Typically, thin detectors on front of calorimeters are called “preshower”. The design goal of such detectors is to count the number of charged particles in order to correct for energy losses. The timing information of “mips” (minimum ionising particles) is not used for particle identifications. Unlike the standard pre-shower detector, we propose not only count mips, but also reconstruct high-precision timing and the position. This timing detector will have a similar granularity as the proposed high-granularity EM calorimeters themselves, but will have a sensor technology and readout which is best suited for mip time stamping (not necessarily for energy reconstruction). Our proposal is to enclose the EM detectors with two timing layers, one - before the first EM layer, and the second is after the last EM layer (but before the HCAL). The two layers of the timing detector allows a robust identification of time by correlating the position and timestamps of the particle passing through the ECAL.

In this paper we will explore this idea using full Monte Carlo simulations. A schematic representation of the positions of the timing layers for a generic detector geometry is shown in Fig. 1

The second layer of the timing detector can be justified if fluctuations of hits times are smaller than the resolution of the timing layers. In order to verify this, we used a full Geant4 (version 10.3) [6] simulation of the SiFCC detector [7] that allows to use the information on hits from the ECAL. The ECAL is built from a highly segmented silicon-tungsten with the transverse cell size of 2×2 cm. The ECAL has 30 layers built from tungsten pads with silicon readout, corresponding to $35 X_0$. The first 20 layers use tungsten of 3 mm thickness. The last ten layers use tungsten layers of twice the thickness, and thus have half the sampling fraction.

To verify that the time differences between last and first layer of ECAL is sufficiently small, and can be neglected for the timing layers that have a timing resolution of the order of 10 ns, a sample of single pions was created with 1 and 10 GeV momenta. The particles were reconstructed in the ECAL calorimeter, and the time difference $\Delta T = T_{\text{last}} - T_{\text{first}}$ of the hits between the last and first ECAL layers was calculated. Only hits that arrive first were considered. Figure 2 shows the time distribution for 1 and 10 GeV pions. It can be seen that the peak positions of the distributions are smaller than 1 ps, as expected for the distance of about 20 cm between the last and first layers¹. More importantly, the RMS of these distributions are significantly smaller

¹The precision with which the simulations were performed are about 0.2-0.3 ns

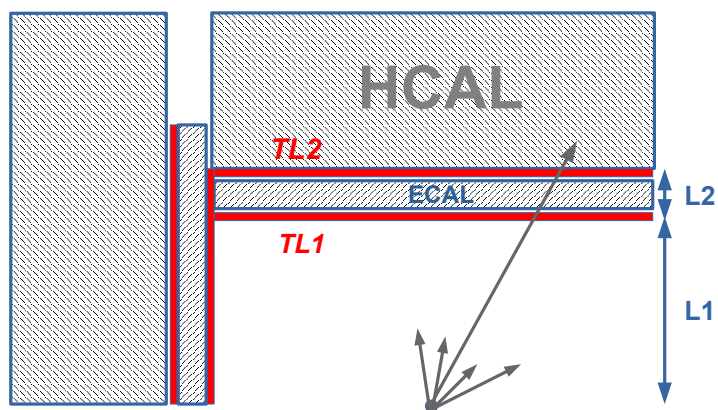


Figure 1: An example of positions of the thin timing layers for a generic detector. The thin timing layers will enclose the electromagnetic calorimeter, allow a reliable reconstruction of the mip signals with a timing resolution of the order of 10 ps.

than the 10 ns. Therefore, for the timing layers that have a resolution of the order of 10-20 ns, a single particle crossing the two layers will be seen as a single simultaneous hit, thus such hits can be well correlated in time and identified as a single crossing particle.

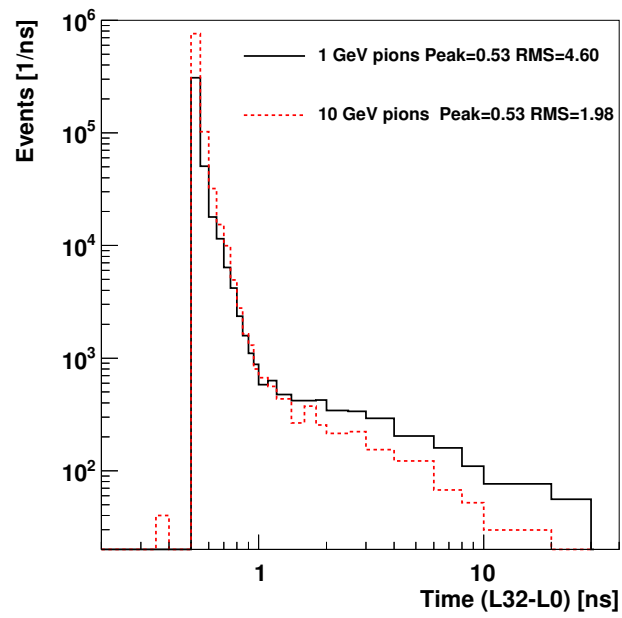
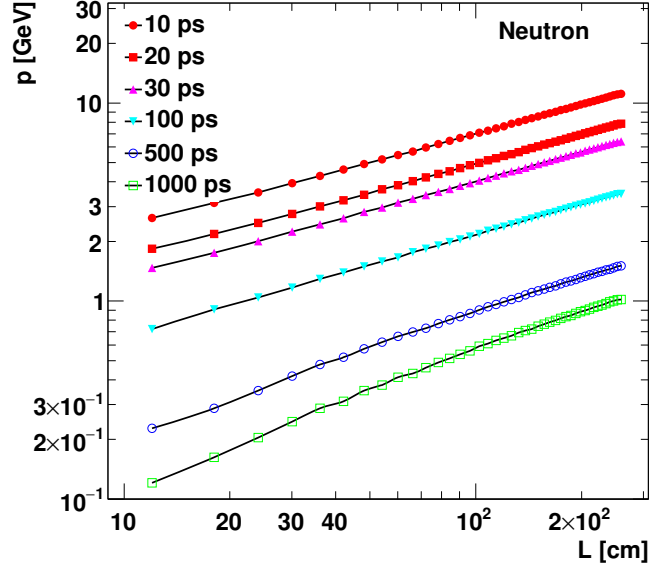


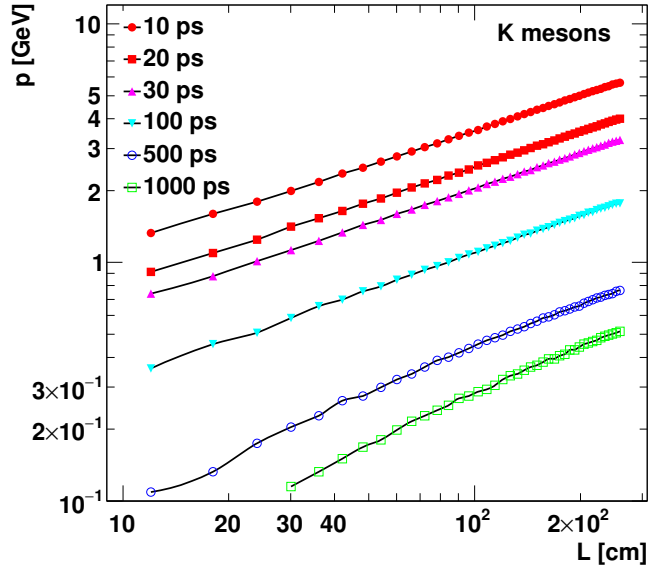
Figure 2: The difference between time of hits between the last and first layer of ECAL for single pions with the transverse momentum 1 and 10 GeV. Only first (fastest) hits were considered

3. Timing layers for single particles

Before considering the full Geant4 simulation, let us discuss the benefit of the TOF information for identification of separate particles. Fig. 3 shows the 3σ separation from the pion mass hypothesis using the same procedure as discussed in [8]. The calculations are performed for several options for the resolution of the timing layer, from 10 ps to 1 ns, as a function of the travel length L and the momenta. For a 20 ps detector and for a typical travel distance of $L \sim 0.2$ m from the interaction point to the electromagnetic calorimeter, neutrons (and protons) can be separated from the pion hypothesis up to 7 GeV. The separation of K -mesons can be performed up to 3 GeV. This momentum range should be sufficient for reliable particle identification in a wide range of physics studies, especially if such identification is used for jets that are dominated by this momentum range of separate particles. For a detector with 1 ns, the separation can only be possible up to 300 – 500 MeV. This is below than a typical minimum transverse momentum of 0.5 – 1 GeV for particles considered for high-energy proton colliders . Therefore, a timing layer with 1 ns resolution cannot effectively be used for particle identification in such experiments.



(a) Neutrons



(b) K -mesons

Figure 3: The 3σ separation from the pion mass for neutrons and K -mesons as a function of the distance and the momenta.

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