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Time Stamping of TPC Tracks in the CLIC_ILD Detector

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Abstract

The TPC measures the z coordinate of the particle trajectory as drift time. In combination with a silicon detector, which directly measures the z coordinate in space, this allows one to determine a time stamp for the reconstructed TPC tracks. We report on the timing resolution which can be achieved using the detailed TPC simulation in the MarlinTPC package.

1. Introduction

The TPC itself does not directly provide a time stamping possibility for reconstructed hits like the silicon sensors because the arrival time of the charge on the end plate is used to reconstruct the z coordinate. The arrival time is always measured relative to the beginning of the bunch train. It consists of the drift time t_{drift} and the time of the bunch crossing within the bunch train.[1)] Hence the measured z coordinate is not an absolute position but also contains the information of the bunch crossing (BX):

$$z_{\mathrm{TPC}} = (t_{\mathrm{drift}} + \Delta t_{\mathrm{BX}} BX) v_{\mathrm{drift}}$$

A silicon detector measures the absolute z coordinate, which corresponds to $t_{\mathrm{drift}} \cdot v_{\mathrm{drift}}$ in the TPC. Combining both measurements allows to determine the bunch crossing BX within the bunch train since the time difference between two bunch crossings Δt_{BX} is known (0.5 ns at CLIC):

$$BX = \frac{\tau}{\Delta t_{\mathrm{BX}}} = \frac{z_{\mathrm{TPC}} - z_{\mathrm{Si}}}{v_{\mathrm{drift}}} \frac{1}{\Delta t_{\mathrm{BX}}},$$

where τ is the reconstructed time stamp. This method does not use any time stamping information from the silicon sensor. It just requires a matching of the reconstructed TPC track with the silicon sensor. The Silicon External Tracker SET has a low occupancy of only 10^{-4} hits per mm^2 and bunch train [1]. This allows for a mostly unambiguous matching between the silicon hits and the TPC track. The position of the TPC track in z is known to be within the bunch train, which corresponds to twice[2)] the bunch train length t_{BT} times the drift velocity: $\Delta z = 2 \cdot t_{\mathrm{BT}} \cdot v_{\mathrm{drift}} \approx 25$ mm.

To get a realistic estimate of the time stamping resolution, the TPC tracks have been simulated and reconstructed with the MarlinTPC software package [2]. It has a detailed simulation and digitisation producing realistic TPC raw data, which subsequently is reconstructed with the same reconstruction chain being used for the LCTPC Large Prototype data. This allows for a maximum of realism. The time of flight in the TPC has not been taken into account, neither in the simulation nor in the reconstruction. After proper simulation and correction the resulting uncertainty should be small for particles coming from the interaction point. A detailed description of the TPC software chain and the parameters used can be found in a dedicated note [3].

For this study single muons from the nominal interaction point have been used. As the matching with the SET hit is trivial for this case, Monte Carlo cheating has been used. The Monte Carlo helix has been extrapolated into a cylinder placed in the middle between the inner and the outer SET layer, taking into account multiple scattering at the outer TPC field cage.[3)] The extrapolated hit has been smeared with different SET resolutions (50 µm, 100 µm and 150 µm) to study its influence on the time stamping accuracy. These values include the alignment uncer-

[1] In the detailed digitisation the shaping of the electronics and the time binning into ADC samples introduces a systematic offset, which also is present in real life. This offset has been determined with an independent Monte Carlo sample and subtracted from the reconstructed drift time.

[2] Not knowing the position of the track inside the bunch train, there can be up to a full bunch train before or after the measured track. Hence the time window is twice the bunch train length.

[3] Multiple scattering in the beam pipe, the inner silicon detectors and the inner field cage are not taken into account. They do not influence this study since the change in the track direction is common for both the TPC and the SET, and only the difference between the two measurements is used.

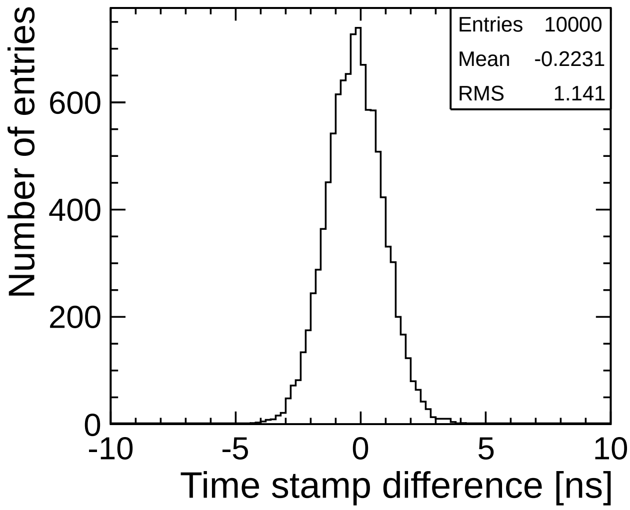

Figure 1: The difference of the reconstructed time stamp and the true Monte Carlo time stamp for single muons with an energy of 50 GeV at an dip angle of 50° with an SET z resolution of 50 µm.

tainty as well as the intrinsic SET resolution.

In this study the time stamping in the barrel region (polar angle $\theta > 40°$) has been investigated. The angle given in the plots is the dip angle $\lambda = 90° - \theta$.

2. Results

Figure 1 shows the difference of the reconstructed time stamp τ and the true time $\tau_{\mathrm{MC}} = \Delta t_{\mathrm{BX}} BX$ for a muon energy of 50 GeV, a dip angle $\lambda = 50°$ and an SET resolution of 50 µm. The time stamping resolution is the width (r.m.s.) of this distribution, which is 1.14 ns in this example.

Figure 2 shows the difference of the reconstructed bunch crossing and the true Monte Carlo bunch crossing for single muon tracks at a dip angle of 5°. The distribution has an r.m.s. of 2.8 bunch crossings, corresponding to 90 % of the tracks to be reconstructed correctly within ± 5 bunch crossings. Due to diffusion, which dominates over the track angle effect in the barrel region, this distribution is slightly wider than the one for $\lambda = 50°$, as the signal has to drift over the full distance from the cathode to the readout, while for the tracks at $\lambda = 50°$ the hits at the outer radii are near the end cap and have a better resolution, resulting in a better track extrapolation into the SET. To study the track angle effect as well as the influence of the track energy (energy dependent multiple scattering) and the SET resolution, samples of 10,000 muons each have been simulated at three different angles in the tracker barrel ($\lambda = 5°$, 30° and 50°), seven different energies from 2 GeV to 200 GeV and four different SET resolutions (0 µm, 50 µm, 100 µm and 150 µm). To see the resolution of the TPC only, the points with 0 µm resolution for the SET have been simulated without multiple scattering in the TPC's outer field

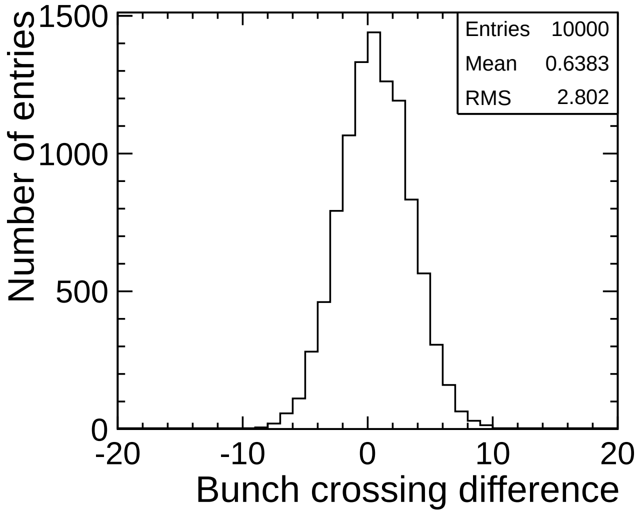

Figure 2: The difference of the reconstructed bunch crossing and the true Monte Carlo bunch crossing for single muons with an energy of 50 GeV at a dip angle of 5° with an SET z resolution of 50 μm.

cage.

The time stamping resolution for the different dip angles as a function of the muon energy is shown in figure 3. All points have been simulated for a constant SET z resolution of 100 μm. The dependence on the energy is weak. Only the points at a muon energy of 2 GeV show a slightly worse time stamping resolution. The resolution for $\lambda = 50^\circ$ is 1.6 ns and goes up to 1.8 ns for steep tracks near the cathode.

The impact of the SET resolution is shown in figure 4. Again the time stamping resolution is plotted against the energy, this time for a constant dip angle of 5 degrees. The TPC combined with a perfect SET resolution and no multiple scattering can provide a time stamping accuracy of 1.3 ns. For an SET resolution of 50 μm the resolution is only slightly degraded (1.5 ns for low and 1.4 ns for higher energies). For an SET resolution of 100 μm the resolution of the TPC and the SET are approximately the same and the resulting time stamping resolution is around 1.8 ns. For 150 μm SET z resolution the time stamping resolution goes up to 2.3 ns and is now dominated by the SET.

Table 1 summarises the time stamping resolution for the three angles in the barrel and the four SET resolutions which have been simulated at three different energies (2 GeV, 20 GeV and 200 GeV).

3. Requirements on the Drift Velocity

All calculations shown in this note use one fixed value for the drift velocity. The impact of uncertainties of v_{drift} on the position measurement should be below 50 μm to be in the same

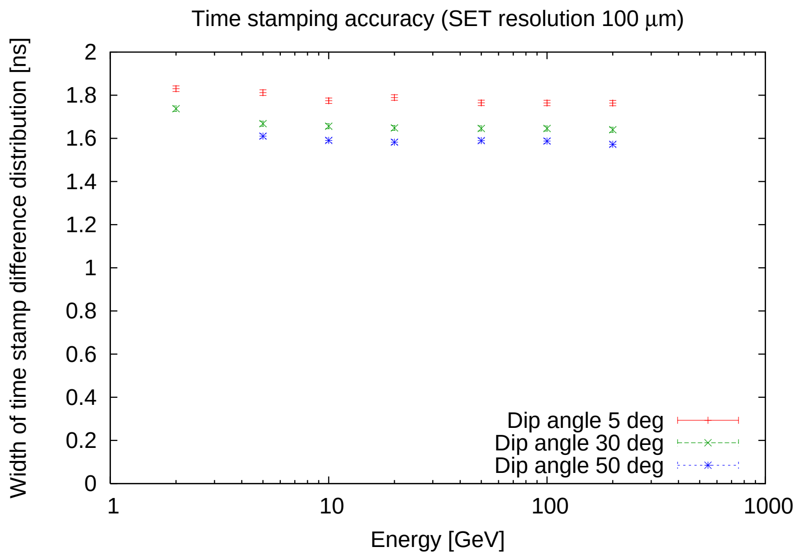

Figure 3: The time stamping resolution as a function of the muon energy for different dip angles and an SET z resolution of 100 µm.

		Energy 2 GeV				Energy 20 GeV				Energy 200 GeV			
		SET Resolution [µm]				SET Resolution [µm]				SET Resolution [µm]			
		0	50	100	150	0	50	100	150	0	50	100	150
Dip angle	5°	1.31	1.46	1.83	2.32	1.24	1.40	1.79	2.29	1.21	1.37	1.76	2.27
	30°	1.17	1.34	1.74	2.25	1.03	1.22	1.65	2.18	1.03	1.21	1.64	2.17
	50°	– [4]	–	–	–	0.94	1.13	1.58	2.13	0.93	1.12	1.57	2.12

[4] Due to the curvature, a 2 GeV muon at $\lambda = 50°$ is not in the barrel region but leaves the TPC through the end plate.

Table 1: The time stamping resolution (r.m.s. in ns) for all simulated dip angles and SET resolutions at three different muons energies.

order as the impact from the SET resolution, which is $2 \cdot 10^{-5}$ of the total drift length. Hence, the drift velocity also has to be known with a relative precision of $2 \cdot 10^{-5}$.

This should be possible because the gas is operated at the maximum of the drift velocity.[5] The

[5] Gas mixtures like the $Ar/CH_4/CO_2$ 93/5/2 gas used in this study show a maximal drift velocity at a specific reduced electric field. This is caused by a quantum mechanic effect know as the Ramsauer minimum of the scattering cross section for electrons in gases [4]. As the derivative at a maximum is zero, the dependence of the drift velocity on the reduced electric field is small near the maximum.

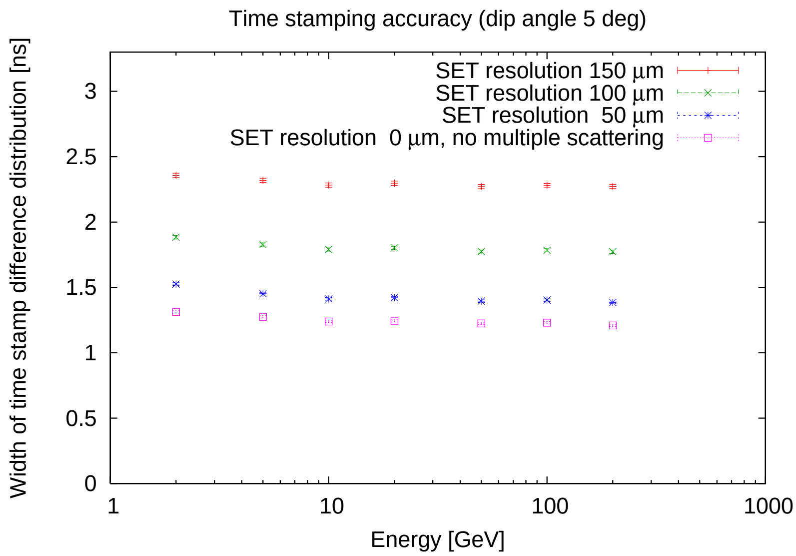

Figure 4: The time stamping resolution as a function of the muon energy for different SET z resolutions at a dip angle of 5 degrees.

drift velocity $v_{\text{drift}}\left(\frac{E}{N}\right)$ near the maximum can be approximated by a quadratic function, where E is the electric field and N is the number density [4], with $N \sim \frac{p}{T}$. The effect of uncertainties on the electric field, the pressure and the temperature are estimated using the parametrisation for $Ar/CH_4/CO_2$ 93/5/2 gas taken from [5], which has a maximum drift velocity of 45.7 mm/µs at $E = 242$ V/cm. For an estimation of the uncertainties we use ± 1 V/cm for the electric field, corresponding to $\Delta E/E \approx 2 \cdot 10^{-3}$, ± 1 K for the temperature, corresponding to $\Delta T/T \approx 3 \cdot 10^{-3}$ and 1 mbar for the pressure, corresponding to $\Delta p/p \approx 1 \cdot 10^{-3}$. This leads to uncertainties of v_{drift} of $3 \cdot 10^{-6}$ from the electric field, $6 \cdot 10^{-6}$ from the temperature and $7 \cdot 10^{-7}$ from the pressure. All these effects are well below the required precision of $2 \cdot 10^{-5}$.

4. Conclusions and Outlook

In combination with the SET, the TPC is able to provide a track time stamp with an accuracy of better than 1.5 ns in the barrel region, assuming an SET resolution of 50 µm (intrinsic resolution and alignment). This result is achieved without using any time stamping information from the silicon detectors. With 10^{-4} hits per mm^2 and bunch train the occupancy in the SET is low enough to allow for a mostly unambiguous matching of SET hits with TPC tracks.

The dependence on the track momentum is negligible, and the dependence on the dip angle in the barrel region is weak. The resolution of the SET has a large impact on the time stamping accuracy. With a z resolution of 50 µm in the SET the time stamping resolution is still dominated by the TPC and the 1.5 ns can be achieved.

In this note only the barrel region and the combination with the SET has been treated. The end cap region is currently being studied. Here a matching can be done with the ETD, but the resolution may be affected by the multiple scattering in the end plate. For tracks going through the readout plane, the TPC could also provide a stand alone time stamp by using the arrival time of the last measured hit, which is known to be at zero drift. As only one hit and not the full track is used, the accuracy of this method will not be as high as the combined measurement with a silicon sensor.

Until now the matching between TPC and silicon detectors has been obtained using Monte Carlo truth information. To show that the matching works in narrow jets, the SET also needs a detailed digitisation, including the projection into strips, charge sharing and ghost hits, to take into account all the possible confusion effects which are required to calculate a reliable matching efficiency.

References

[1] D. Dannheim and A. Sailer. Beam-induced backgrounds in the CLIC detectors. LCD-Note-2011-021, 2011.

[2] MarlinTPC, Marlin based simulation, digitisation, reconstruction and analysis code for the TPC. Website: `http://ilcsoft.desy.de/portal/software_packages/marlintpc/`.

[3] M. Killenberg. Software and parameters for detailed TPC studies in the CLIC CDR. LCD-Note-2011-025, 2011.

[4] W. Blum, W. Riegler, and L. Rolandi. *Particle Detection with Drift Chambers, Second Edition*. Springer, 2008.

[5] M. Killenberg. *Resolution Studies of a GEM-Based TPC*. Ph.D. thesis, RWTH Aachen University, 2007. urn:nbn:de:hbz:82-opus-18020.

A. Software List

This sections lists the software which has been used for this study. A detailed description of the packages and a list of all the parameters can be found in a dedicated note [3].

A.1. Simulation

- `PrimaryIonisationProcessor`

A.2. Digitisation

- `DriftProcessor`
- `GEMProcessor`
- `ChargeDistributionProcessor`
- `TPCElectronicsProcessor`

A.3. Reconstruction

- `PulseFinderProcessor`
- `HitTrackFinderTopoProcessor`
- `TrackSeederProcessor`
  First run to calculate the initial track parameters before outlier rejection.
- `HitsInTracksSplitterProcessor`
- `OutlierRejectionProcessor`
- `TrackSeederProcessor`
  Second run to calculate the final parameters after outlier rejection.