ATLAS RPC time simulation and off-line calibration

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We demonstrate that a time resolution very similar to the RPC single unit resolution can be achieved by applying simple offline calibration algorithms over the whole RPC system of ATLAS and in spite of time varying in-time and out-of-time background conditions, by applying the calibration procedure to the whole 2011 data set, where the average number of interactions per beam crossing increased from about 5, observed in Spring, to about 18 at the end of the run period. The precise time measurement allows to the ATLAS RPC detectors to provide an independent "forth" coordinate that can be used to suppress background hits and to measure the particle velocity thus enhancing the discover potential for Physics beyond the Standard Model with non-prompt signatures.

The Resistive Plate Chambers (RPCs) [1] are planar large size gaseous detector working in saturated avalanche regime with resistive electrodes and with orthogonal pick-up readout strips located outside the active gas volume. The excellent time resolution is due to the constant and intense electric field across the thin gas gap which entails charge multiplication just after the elementary ionization process takes place. In the ATLAS experiment three layers of RPC detectors are used in the Muon Spectrometer barrel ($|\eta| < 1.05$) to generate a hardware muon trigger signal. There are 1116 RPC single units for 26 different topologies, a total active surface of about 4000 m^2, and about 330,000 electronic channels

The On-detector trigger readout electronics, based on the Coincidence Matrix ASIC (CMA), operate to a clock frequency of 320 MHz, corresponding to eight times the 40 MHz bunch crossing clock, allowing for a digitization time resolution of about $\frac{3.125ns}{\sqrt{12}} = 0.9$ ns. The on-line time alignment is done with tracks both for trigger hits and readout hits in order to maximize trigger efficiency.

A simple RPC standalone tracking is implemented off-line and based on RPC space points, which are defined by adjacent hits (clusters) on both orthogonal views but same gas volume [2]. The tracks are straight lines defined by six space points with 1.5 average cluster size per view with 1 cm space resolution. A cut on the global chi2 per degree of freedom is equivalent to select high transverse momentum tracks.

In order to reach the good RPC time resolution it is necessary to establish a time calibration procedure correcting for several effects. These are the particle time of flight, the spread of the *pp* interaction point, the signal delay along the readout strips and fixed hardware delays (cables, optical links, configuration, ...). The fixed delay can be measured once and absorbed into the calibration constant. The signal delay along the readout strips must be evaluated for each hit using two views spatial correlation. The delay is given by the signal propagation speed times the distance from the readout electronics (given by the orthogonal coordinate). Finally, the time of a crossing track is defined as the minimum time of the adjacent hits belonging to the cluster.

In the simulation, the time of the RPC hits is emulated in such a way to reproduce the expected measurement in a perfectly timed in system. The components contributing to the time are the time of flight from the interaction point, evaluated by GEANT4 in the particle propagation process and the time of the signal propagation along the strip ((v=208 mm/ns)), a gaussian smearing of 1.5 ns is applied to reproduce jitter effects (RPC H8 test beam resolution [3]). The time of flight for a prompt muon hitting the center of the strip is then subtracted to the time computed so far, to reproduce the compensation for relative delays between different detector components implemented in the firmware. Finally, an arbitrary offset is added in order to obtain the time distribution for prompt muons well centered into a 200 ns wide readout window. In the time simulation process the dead time programmed in the readout electronics is emulated by killing hits closer than 100 ns to any previous hit on the same strip; this allows to remove after-pulsing due to energy deposited by delayed secondary ionization processes in the gas. Finally, the time is converted into a discrete measurement according to the finite resolution (3.125 ns) of the electronics and the strip index is converted into one or more electronic channel indices, by simulating the signal splitting or merging induced by a fully realistic mapping of the physical channels into electronic

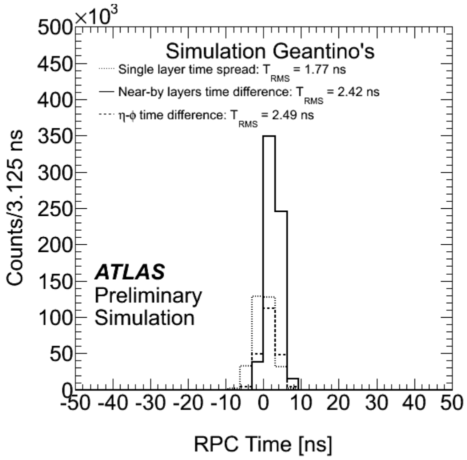

Figure 1. Distribution of RPC cluster time with signal time propagation along strip subtracted (dotted line). Distribution of RPC cluster time difference between two near-by gas volume for the same view (continuos line). Distribution of RPC cluster time difference with signal time propagation along strip subtracted between orthogonal view belonging to the same gas volume (dashed line). The RPC hits are simulated with not-interacting neutral tracks (Geantino's).

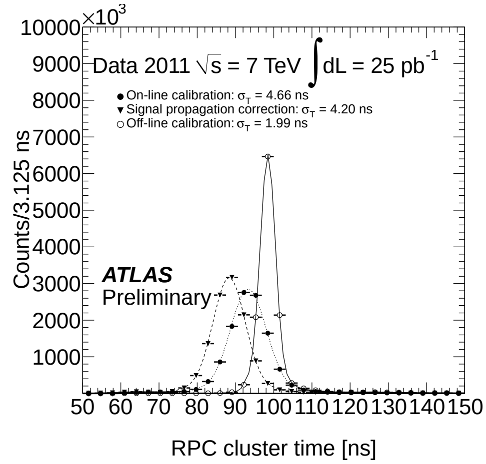

Figure 2. Distribution of RPC cluster time after on-line calibration (full circles). Distribution of RPC cluster time with signal delay propagation along strip subtracted (triangles). Distribution of RPC cluster time with signal delay propagation along strip subtracted after off-line calibration (open circles). The results of the fit explained in the text are superimposed on the data points.

registers.

We verify the RPC time simulation and reconstruction algorithms simulating Geantino tracks without interaction point spread. Geantino's are not-interaction and neutral tracks, which leave hits in active volume but does not create secondary interactions and does not bend in magnetic fields. In Figure 1 several key distributions of RPC cluster time due to one million simulated Geantino tracks are shown. The root mean square values are reported and correspond to the values expected from a back-on-the-envelope calculation assuming a time resolution of 1.75 ns (1.5 ns RPC time resolution in quadrature with 0.9 ns time resolution digitization) and an independent time fluctuation between different gas volumes and views ($1.75\sqrt{2} = 2.47$ ns relative time spread).

We defined as off-line calibration criteria that the arrival time of a relativistic track leaving the interaction point, after signal time delay subtraction, is in average centered in the readout window. This is, after signal time delay subtraction, a prompt track has an arrival time of 100 ns. We used as signal propagation speed along readout strip the nominal value of 200 mm/ns and used a simple and trivial calibration algorithm strip by strip. The calibration constant per strip is defined by the maximum value of the strip time after time signal delay subtraction distribution and adding the conventional 100 ns readout window center.

The 330,000 thousand calibration constants were measured adding together several runs of June 2011. The so obtained single strip off-line time resolution was stable for all channels and for all 2011 periods up to period K (corresponding to an integrated luminosity of about 2.4 fb^{-1})). After that, RPC time configuration were changed several times to improve the trigger efficiency. For the remaining periods L and M (highest luminosity 2011 runs corresponding to an integrating luminosity of about 2.4 fb^{-1}) sub-period calibration constants are require in order to cope with several change of configurations during the data taking.

Figure 2 shows the achieved time resolution by the off-line calibration. The time distributions are obtained from a muon stream run not used in the calibration constant extraction. The data selection is based on RPC clusters matched with at least one extrapolated muon combined track in both views (dη¡0.1 and dϕ¡0.1). It turn out that the time resolution obtained by on-line time alignment is of 4-5 ns, which corresponds to a resolution of 3.5-4 ns after signal time delay subtraction, and the time resolution obtained after off-line calibration is of 1.9-2 ns to be compared with the ideally expected 1.75 ns. The electronic noise and the time-walk introduced by analog and digital part coupling are expected to make-up the rest of the time resolution. This is a very significant results because obtained for the whole ATLAS, many months of data taking, using a small calibration sample also excluded from the plots,

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