ATLAS RPC detector simulation

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Nowadays, high energy experiments, in order to pursue their discovery and precision measurement goals, rely on detailed simulation software, where the known physics processes and sub-detector response are carefully reproduced with Monte Carlo techniques. The simulation software of the ATLAS experiment is a very complex package developed by many researchers[1].

The simulation software chain is divided into three steps: generation of the final state of the emulated physics process (in terms of kinematics of the particles emerging from the scattering), physics interaction of the final state particles with the detector materials, and digitization of the energy deposited in the sensitive regions into detector hits. The output of the simulation chain is reconstructed by the same software packages used for real data.

The digitization step is detector specific. The detector hits are determined by the physics process responsible of the signal formation and the electronic chain converting the signal into a count for a specific detector channel.

In the ATLAS experiment, outstanding standalone muon identification and momentum resolution are achieved with a large volume Muon Spectrometer embedded into an air core toroidal magnetic field. Three layers of resistive plate chambers (RPC) in the barrel ($|\eta|$ <1.05) generate the muon trigger, allow bunch-crossing identification, and measure the muon trajectory in the non-bending plane of the spectrometer magnets.

RPC's are planar large size gaseous detector working in saturated avalanche regime with resistive electrodes and with panels of orthogonal pick-up readout strips located outside the active gas volume. The simulation of RPC were implemented in a parametrized way to reproduce as much as possible the detector response to real events without relying on the detector physics phenomena which are not well known from first principles.

The response of the RPC detector to minimum ionizing particle are well characterized in real measurements with cosmic ray and collision events. We took advantage of this and implemented data driven RPC simulation tuned on the LHC 2010 collisions data.

The event generators simulate different types of events: hard scattering signal, minimum bias, beam halo, beam gas, cavern background, and cosmics. The GEANT4 simulation package propagate stable and quasi-stable particles originated from the interaction points through the detector by multi-steps trajectories. At each step, interactions with the materials and decays are evaluated on statistical basis and the produced secondary particle are added to the particle list to be further propagated. The single particle propagation stops when the energy, degraded by the interactions with the traversed media, falls below a particle dependent cut-off.

The RPC sensitive volume is defined by the gas layer where the high voltage is applied. The physics process induced by the GEANT4 hit is not simulated but simply converted in two orthogonal readout strip positions using the ATLAS Geo-Model package and without applying any energy threshold cuts.

The RPC system must select on-line events containing high transverse momentum muons with high efficiency, limited fake rate, and with the correct timing in order to reconstructed the good event candidate.

The effective digital detector response is introduced by the measured two-view-correlated readout detection efficiency for each gas volume and parametrized by three numbers varying from 0 to 1: both views detection efficiency ($\epsilon_{\eta\wedge\phi}$), first view only ($\epsilon_{\eta\wedge\bar{\phi}}$) and second view only detection efficiency ($\epsilon_{\phi\wedge\bar{\eta}}$). These three parameters correspond to three mutually exclusive possible detector responses and, along with the probability of unresponsive detector, can be mapped onto four disjoint intervals in the [0,1] range. A random number varying from 0 to 1, according to a flat distribution, is used to decide wether the strips in the (η, ϕ) pair have to be turned on or off and in which combination. This method allows a simple implementation of the two views correlation as measured from data. In Figure 1 the measured detection efficiency for different RPC layers and views from real data and from two simulated benchmark signal samples are shown and the agreement is quite satisfactory.

It is important to simulate the correct hit mul-

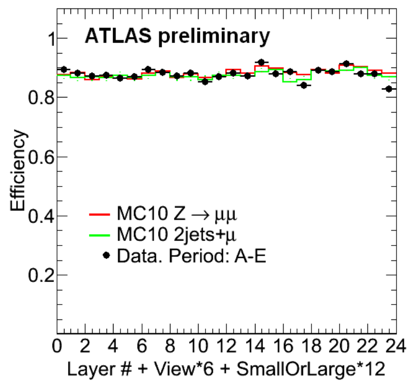

Figure 1. ATLAS RPC average detection efficiency measured from real data and simulated Monte Carlo samples for different layers and views.

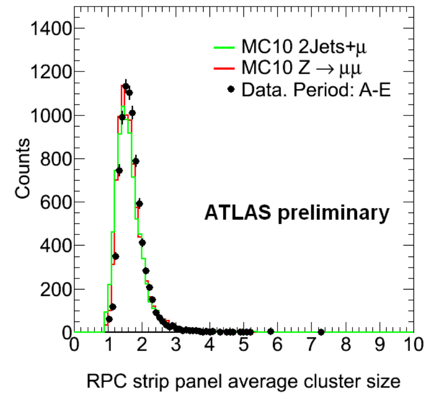

Figure 2. ATLAS RPC average readout panel hit multiplicity measured from real data and simulated Monte Carlo samples.

tiplicity associated to a minimum ionizing particle crossing the sensitive gas gap, in order to assess trigger occupancy and combinatorial coincidences. The hit multiplicity distribution has been approximated by taking into account a twofold behavior: charge sharing considerations are used to define the probability of single and double strip clusters; higher cluster multiplicities are generated according to an exponential decay low adapted to the observed rate of such phenomena in each strip panel. This choice requires a limited number of parameters for each readout panel while allowing to reproduce the typical detector behavior. The hit multiplicity is assigned to the considered strip in several steps. First, the charge sharing effect or the high multiplicity effective emulation is statistically assigned, according to the measured fraction. If the charge sharing is chosen, the multiplicity is deterministically defined by the track position. The cluster size is two if the distance of the track impact point from the closest boundary between two strips is smaller than the readout pitch multiplied by the ratio between the fraction of cluster size two and cluster size one or two. If instead, the tail distribution is chosen, the multiplicity is randomly extracted from an exponential distribution and a symmetric population is assigned around the strips multiplicity (for even multiplicity the one strip asymmetry is randomly assigned to right or left). In Figure 2 the average readout panel multiplicity measured in real data and in two simulated benchmark samples are shown. Also for this quantity the agreement between data and simulation is excellent.

The time alignment of the RPC system is challenging due to the 1 ns resolution of detector and electronics; moreover it is complicated by the strong coupling between the timing of the RPC detector and the RPC trigger related to the shared electronics which accomplishes, at the same time, the readout and trigger tasks. 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; a gaussian smearing of 1.5 ns is applied to reproduce jitter effects. 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 registers.

REFERENCES

1. "The ATLAS Simulation Infrastructure" The ATLAS Collaboration (G. Aad et al.) The European Physical Journal C - Particles and Fields 70, 823-874 (2010).