GEANT4 MUON DIGITIZATION IN THE ATHENA FRAMEWORK

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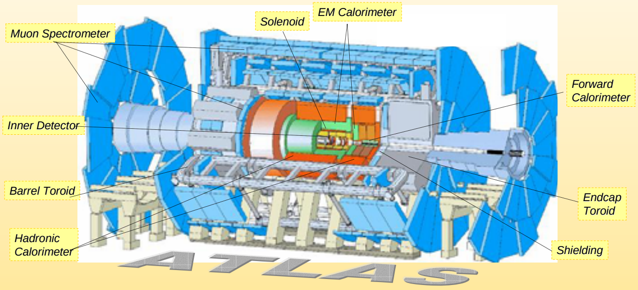
ATLAS Detector and its Simulation

The **ATLAS experiment**, one of the biggest and most complex ever designed, requires a detailed and flexible simulation, developed in an Object-Oriented environment, to cope with design optimization, fast navigation and tracking.



The Full Simulation of the ATLAS Detector consists of a collection of independent modules, developed separately by the different subdetectors, to be loaded on demand as separate libraries: Inner Detector -Tile and Electromagnetic Calorimeters - Magnet System - **Muon Spectrometer**

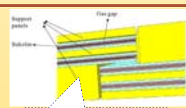
The Muon Spectrometer Simulation

The Muon Spectrometer is a large and complex system relying on several detector technologies

- **Precision Chambers**
  Monitored Drift Tube chambers (**MDT**s) in the barrel and in the endcap regions - Cathode Strip Chambers (**CSC**s) in the innermost ring of the endcap stations
- **Trigger Chambers**
  Resistive Plate Chambers (**RPC**s) in the barrel region - Thin Gap Chambers (**TGC**s) in the endcap region

Simulation of an **MDT chamber** with two **RPCs**

The simulation of muon events requires a very careful description of these active detectors and their functionalities in full details, together with a precision description of the passive materials (toroids, shields, etc.) present in the muon region



Simulation of the RPC internal structure

Muon Digitization

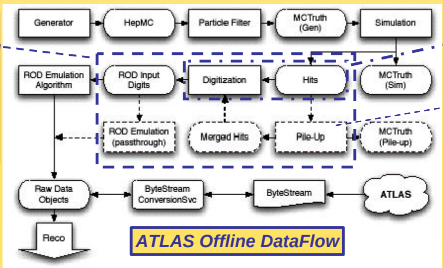
The Muon Digitization is the simulation of the Raw Data Objects (RDOs), or the electronic output, of the Muon Spectrometer. It has been re-written to run within the ATHENA framework and to interface with the Geant4 Muon Spectrometer Detector Simulation. The code is in the cvs repository under offline/MuonSpectrometer/MuonDigitization.

The **Muon Digitization** process consists of **two steps**:

1. the output of the Muon Simulation, henceforth referred to as **Muon Hits**, is converted to **Muon Digits**, i.e. intermediate objects that can be fed into the reconstruction
2. the **Muon Digits** are converted into **RDOs**, the transient representation of the raw data bytestream. This step is realized by means of ATHENA Converters, which take into account of cabling and readout

MuonDigits

1. are defined by the reconstruction group
2. resemble the detector output
3. are converted in RDOs before undergoing permanent writing (POOL persistification)



ATLAS Offline DataFlow

Here, only the detailed implementation of the **first step** of the MuonDigitization, where the detector simulation output (**Muon Hits**) is "digitized" into **Muon Digits**, is described

Pile up with minimum bias and cavern background events

In additiion to handling hits coming from a single bunch crossing, **the MuonDigitization is also able to treat piled-up collisions**. Before Undergoing the conversion to Muon Digits, hits from several bunch crossing are overlaid taking into account the globalTime of the hit plus the bunch crossing time w.r.t the main crossing.

The pile-up model can also handle the cavern background → cavern background and min bias hits are merged together to the signal hits at the digitization level

From Muon Hits to Muon Digits

MuonHits and Simulation Identifiers for the four Muon technologies

	MDT	RPC	TGC	CSC
SimID	StationName, PhiSector, ZSector			
	MultiLayer Layer Tube	DoubletZ DoubletR GasGapLayer DoubletPhi MeasuresPhi	GasGap	ChamberLayer WireLayer
Muon Hit	SimID globalTime driftRadius localPos (trackNumber)	SimID globalTime localPos (trackNumber)	SimID globalTime localPos dirCos (trackNumber)	SimID HitStart HitEnd partID (trackNumber)

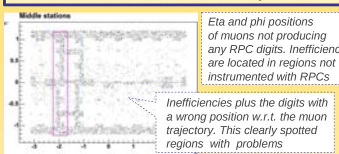
OIDs, Muon Digits and Raw Data Objects RDOs for the four Muon technologies

	MDT	RPC	TGC	CSC
OID	stationName, stationEta, stationPhi, technology			
	multiLayer tubeLayer tube	doubletR doubletZ doubletPhi rpcGasGap rpcMeasuresPhi rpcStrip	tgcGasGap isStrip channel	chamberLayer wireLayer cscMeasuresPhi cscStrip
Muon Digit	OID TDC count (ADC count)	OID propTime globalTime	OID	OID charge
RDO	fired tube	fired channel of CM	raw hit or raw coincidence	4 ADC samplings + strip address

Digitization Validation

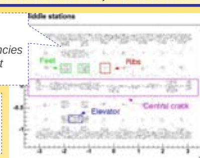
General method: compare known ('true') track position with associated digit position (from MuonGeoModel) and study residual distributions

Many problems has been found and fixed, thanks to this validation procedure (e.g., wrong ID's in BOF RPC chambers, memory leaks in RDO converters)



Eta and phi positions of muons not producing any RPC digits. Inefficiencies are located in regions not instrumented with RPCs

Inefficiencies plus the digits with a wrong position w.r.t. the muon trajectory. This clearly spotted regions with problems



RTT (RunTime Test) is running every nightly build on the digitization algorithms to perform a DigitValidation

Single Muon Technology Digitization

The digitization procedure occurs separately for each Muon technology, MDT, CSC, RPC and TGC. Here the main steps of each MuonHits to Muon Digits conversion are outlined.

MDT Digitization

The **MDT Digitization** consists of several steps

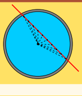
1. conversion from drift radius to drift time
2. calculation of the time structure of the event drift time (+ ADC charge) + time of flight, + bunch time relative to the current bunch + propagation delay of the signal with respect to the tube readout side + dead time
3. trigger match for the digits
4. conversion of total time into TDC counts

3. Trigger match

Digits coming from hits in the masked window are marked "masked"and will haveTDC and ADC counts set to zero

Hits in the matching window will produce normal digits

If an hit lies outside of both windows no Digit is created



1. Dead time calculation

For a given tube the hits are sorted on time (drift + tof + prop + bunch)

From the first hit the deadtime = time_hit1 + dead-window is initialized (the deadtime is 700ns)

No additional hits will be created if the time of a second hit is smaller than the deadtime

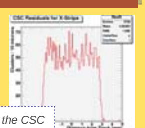
If a hit with t > deadtime is found the deadtime is reset to: deadtime = time_hit2 + dead-window

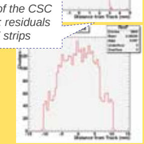
CSC Digitization

The **CSC Digitization** simulates the charge distribution on the CSC cathode strip, identifying strip numbers and orientations.

This occurs in different steps:

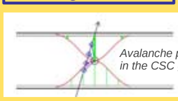
1. Charge calculation on a strip together with the strip OID
2. Simulation of the raw data, i.e. the output of the electronics





Validation of the CSC Digitization: residuals for X and Y strips

1. Charge simulation



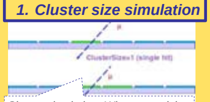
Avalanche production in the CSC gas

2. Time response

CSC amplifier signal shape

RPC Digitization

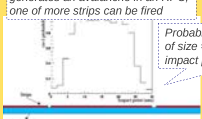
1. Cluster size simulation



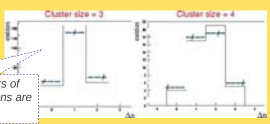
Cluster simulation: When a particle generates an avalanche in an RPC, one of more strips can be fired

The **RPC Digitization**

1. calculates the propagation time of each electronic signal along the strip, from the Rpc Hit position information
2. computes the global time of the digit, adding the propagation time to the time of flight
3. perform the cluster size simulation



Probability to have a cluster of size = 1 as a function of the impact point along the strip



Cluster spread distributions for clusters of size 3 and 4 – experimental distributions are used to decide the size of the cluster

TGC Digitization

The **TGC Digitization** simulates the following detector responses:

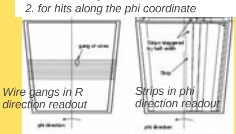
1. multi hits due to tracks passing several wire gangs
2. intrinsic time response, signal propagation along wires and strips
3. detector efficiency (sensitivity) of wire gangs and strips

2. Time response

Simulated time response distribution of TGC as a function of the incident track angle

The TGC Digitization, is done independently

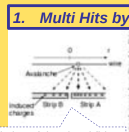
1. for hits along the R coordinate
2. for hits along the phi coordinate



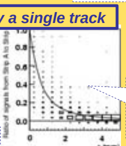
Wire gangs in R direction readout

Strips in phi direction readout

1. Multi Hits by a single track



Simulation of the signal firing two neighboring strips



Scatter plot of ratio of signals from neighboring strips as a function of the position of the avalanche