A Receiver System for Detecting Calorimeter Signals Under Low Signal-to-Noise Ratio Conditions

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Summary

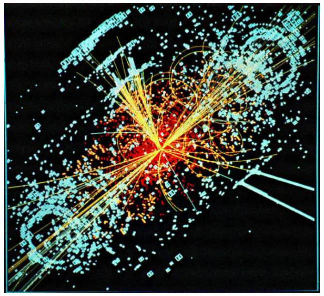
- Introduction
- Experimental tests: motivation
- Receiver Design
- Matched filtering
- Conclusions and ongoing analysis

Introduction

- High Energy Physics
  - Probe into the heart of matter
    - *Supersymmetry, CP violation, beyond the Standard Model, Higgs Boson*
  - Particle accelerators
    - *Collisions at high energy*
    - *Window to explore the fundamental laws of particle physics and the deep structure of space and time*
  - Particle detectors
    - *Extremely segmented*
    - *High complexity and forefront technology*
    - *Engineering challenges*

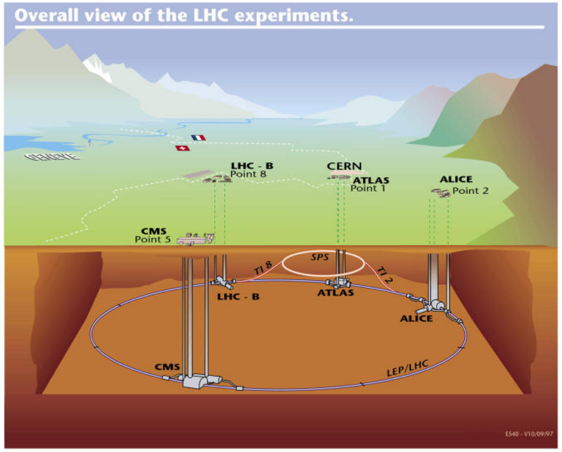
CP violation

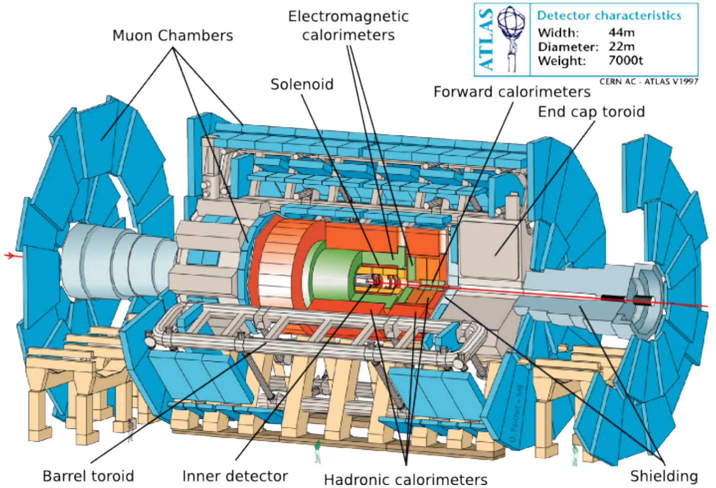
Collision Event



LHC and the ATLAS experiment

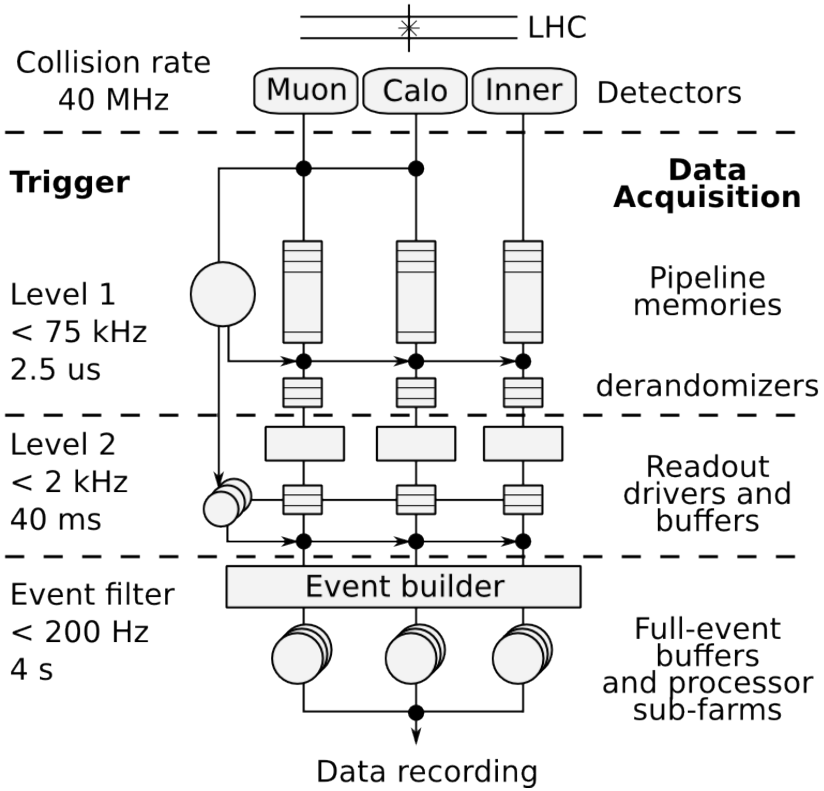
- The Large Hadron Collider
  - Extremely rare signals
  - Huge background contribution
  - Proton collisions at high rate (40 MHz)
  - High luminosity: pile-up contributions
- The ATLAS detector
  - Tracking, Calorimetry, Muon Spectrometer, Magnet System
  - Total data flow of 60 TB/s
  - On-line event filtering (trigger) mandatory





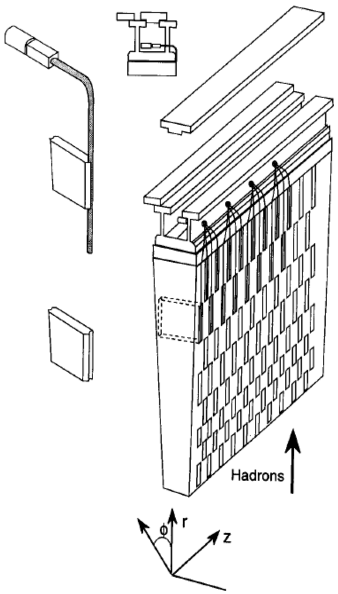
The ATLAS Trigger System

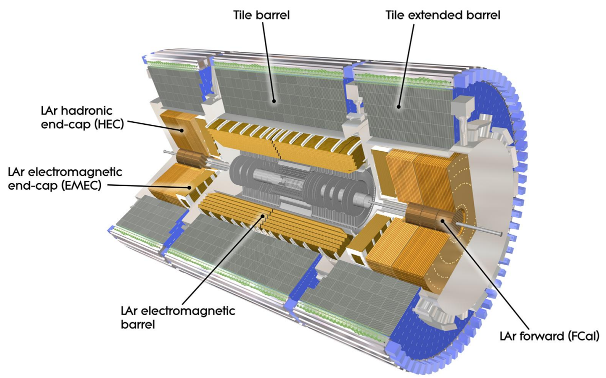
- Three cascaded levels
  - Event rate
  - Latency time
- First level (L1)
  - Hardware
  - 2.5 µs for decision
  - Uses coarser detector granularity
  - Muon and calorimetry
  - Muons: messengers of interesting events

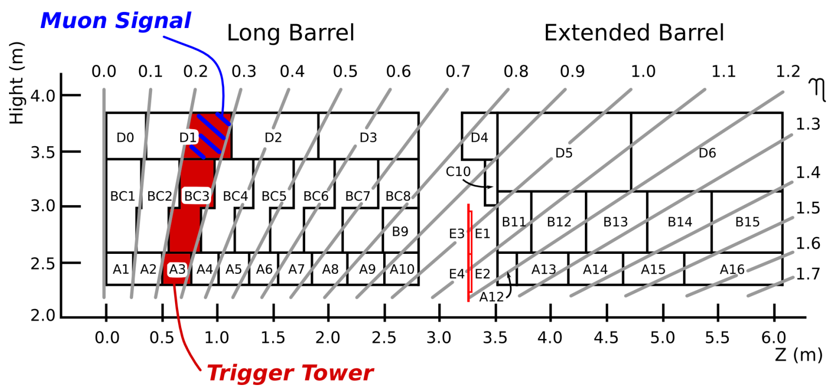


The ATLAS Tile Calorimeter

- Hadronic calorimeter for the ATLAS barrel region
- Energy measurement of produced hadrons, jets, missing energy and muons
- Cell geometry divided into layers and trigger towers
  - 10,000 readout channels
  - Double readout per cell (redundancy)
- L1 Trigger interface signals
  - Tower: analogue summing of signals within a trigger tower
  - Muon: amplified signal from the last layer cell

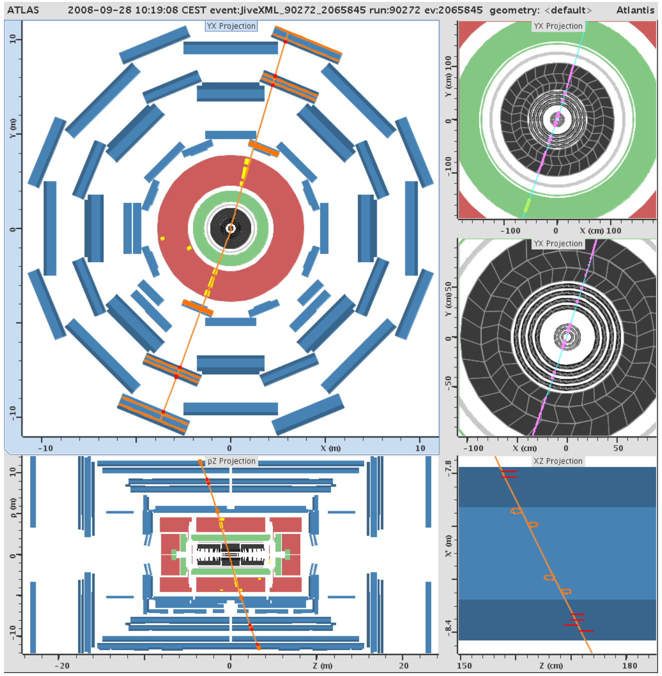






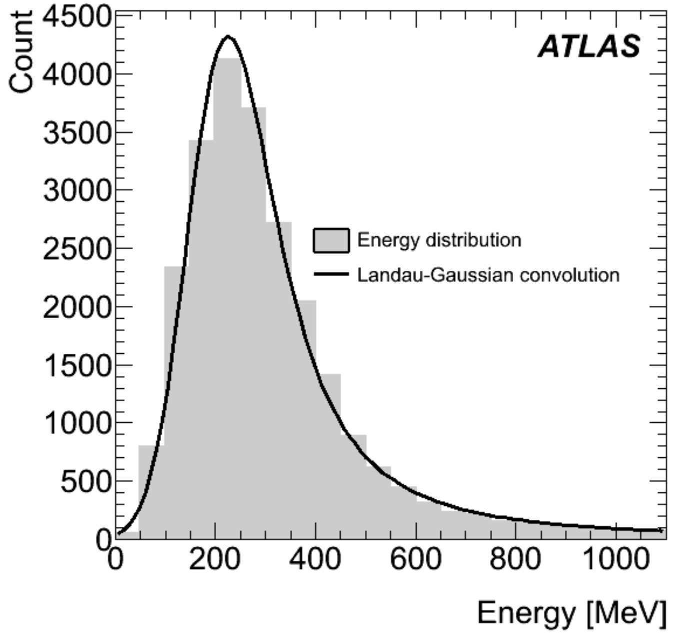
L1 Muon Detection

- Muon Spectrometer
  - Resistive Plate Chamber (RPC) detector (barrel)
  - Intensive magnetic field
    - *Momentum measurement*
  - Detection can be affected by cavern background (muons from cosmics rays and radiation effects)
- Tile muon detection
  - Use of the Tile muon signal
    - *Very low signal-to-noise ratio (SNR)*
  - Confirm the RPC decision
    - *Further reduce of high trigger rates due to cavern background*

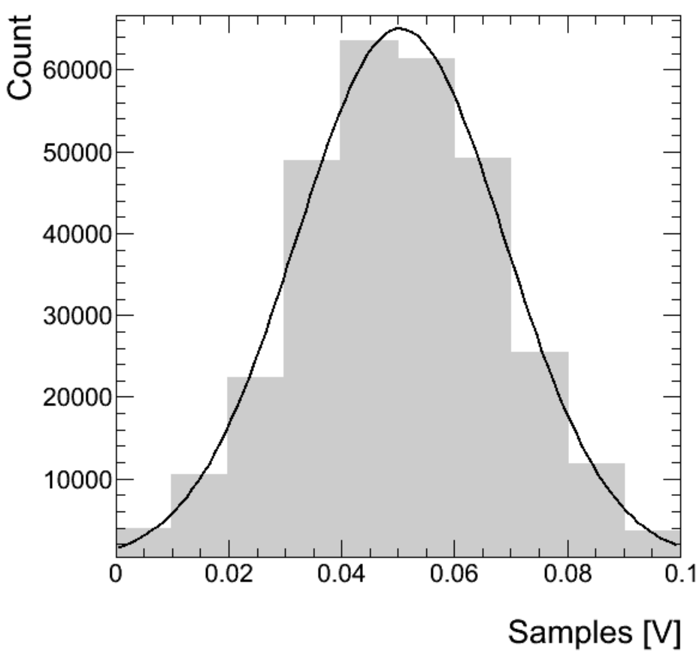


Experimental Tests

- Muons of fixed energy impinging Tile at different angles
- Muon signal acquired by Flash ADC's (8 bits at 40 MHz sampling rate)

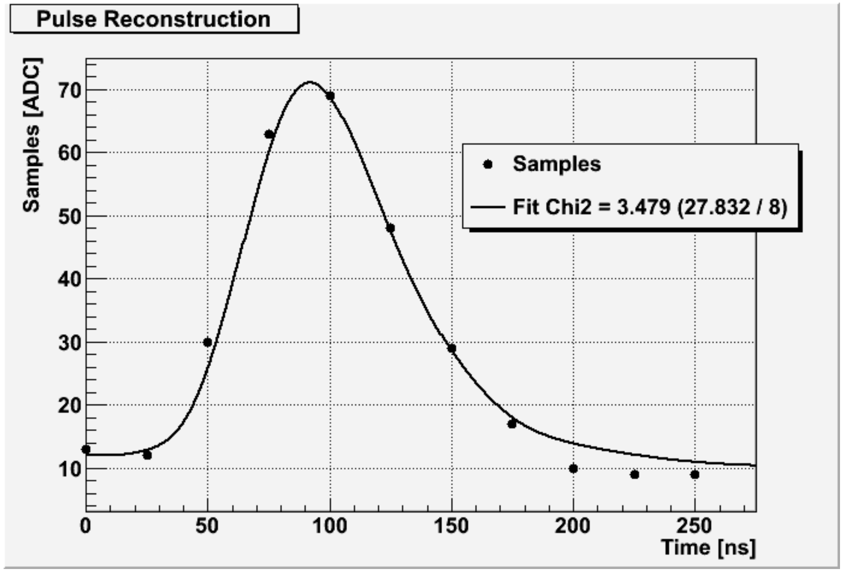


Noise Samples (~6.5 GeV/V)

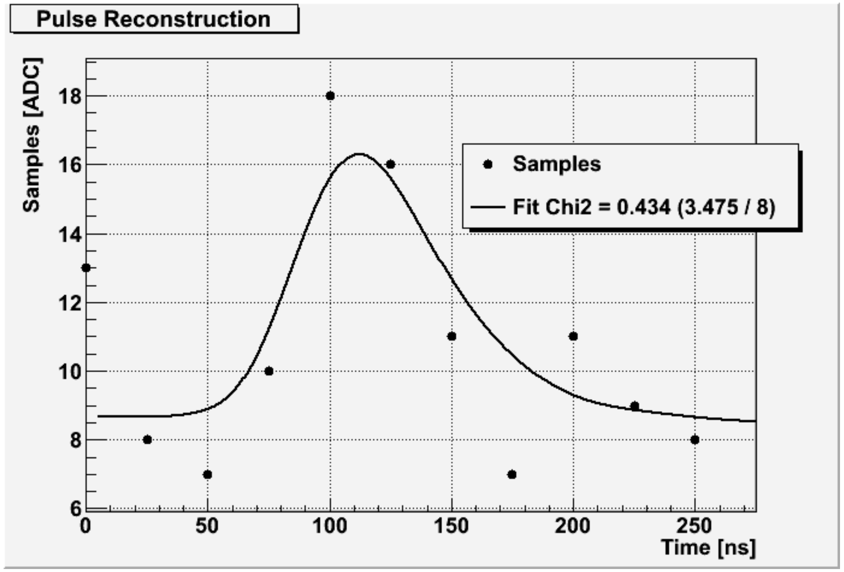


Experimental Tests (2)

- Software sum of both signals from the same cell
- Off-line energy reconstruction (LMS fitting of typical pulse)



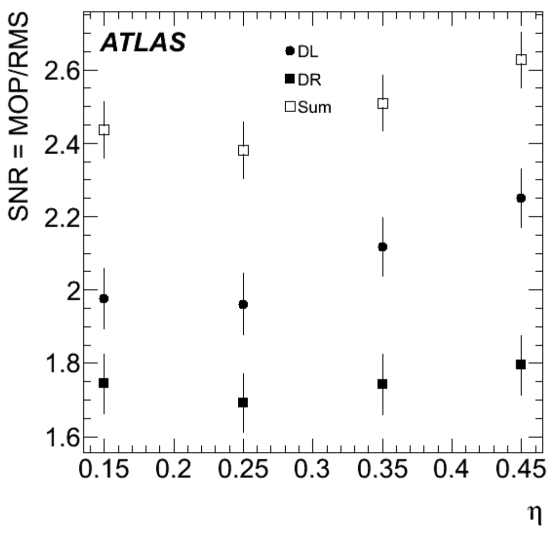
High energy pulse

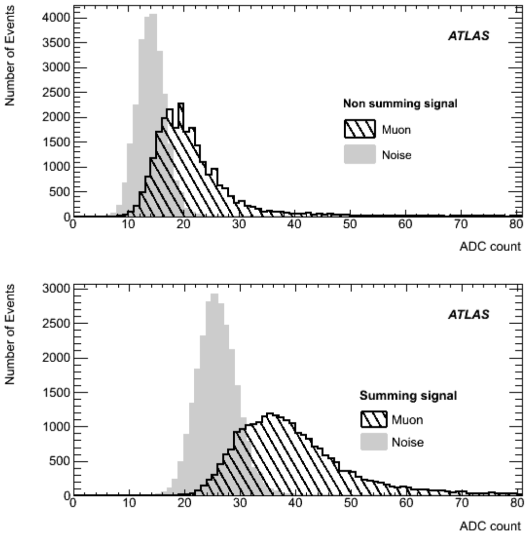


Low energy pulse

Experimental Tests (3)

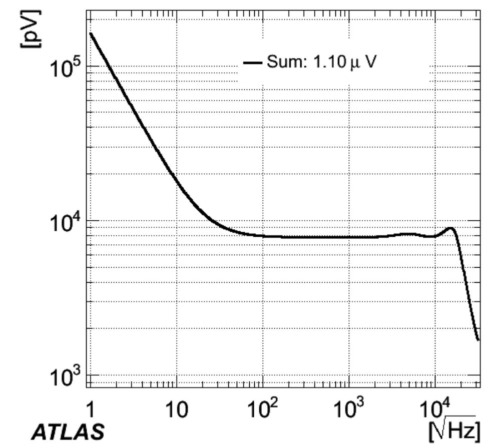
- SNR: MOP from muon energy deposition / Noise energy (RMS)
- Non summing signals from left (DL) and right (DR) readouts with smaller SNR
  - Difference arises from experimental fluctuations
- SNR increase with |η| due to longer muon response (MOP) increase with muon path in deeper cells
- Threshold detector shows smaller confusion area when the summing signal is considered



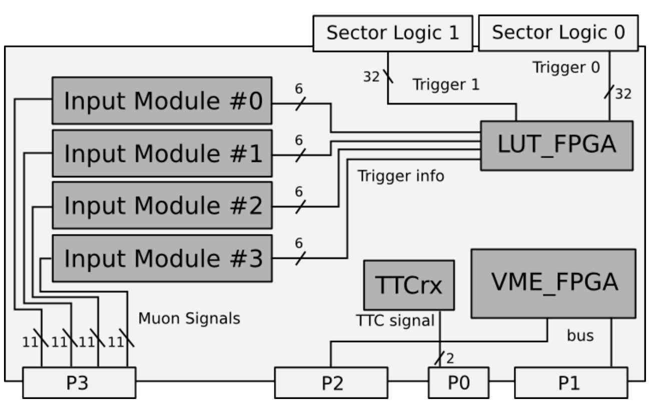


Receiver Design

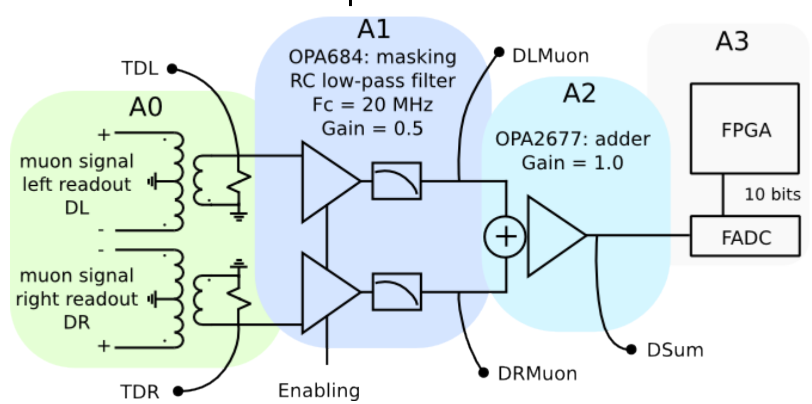
- Analogue summing of muon signals from the same cell
- 40 MHz digitization (10 bits)
- Noise spectrum by Pspice simulation
  - Circuit noise negligible with respect to input noise



Receiver Module

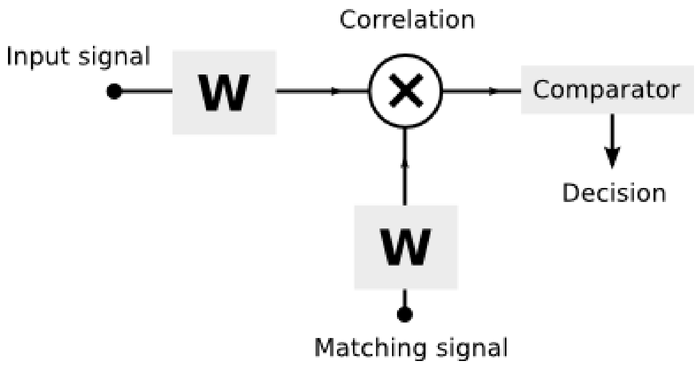


Input Module



Receiver Design (2) – Signal discrimination

- Experimental signals simulated by Pspice at the Input Module
- Noise and muon signals (25,000 each)
- Split datasets: development and evaluation
- Threshold detector
- Matched filter detector
    - Simplified design (on-line implementation)
    - Gaussian noise consideration
        - *Whitening stage*
    - Matching signal: mean muon estimation from signal samples



Whitening

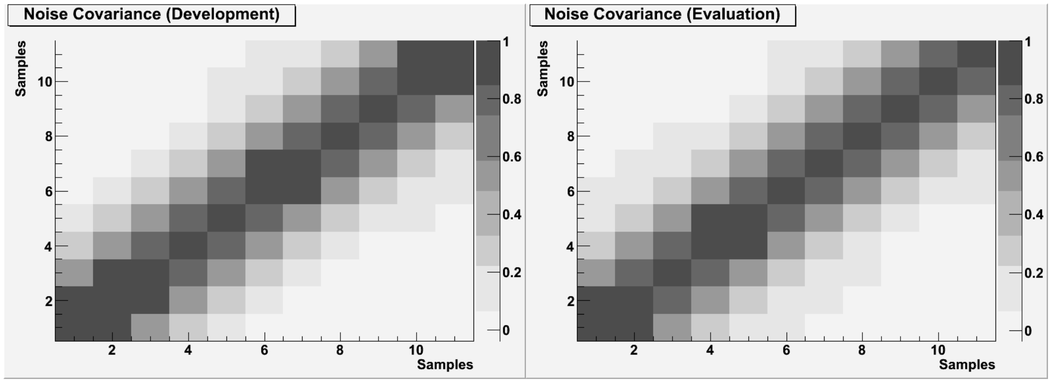
- Noise covariance from development set
- Linear transformation for whitening
- Evaluation dataset: good generalization from the development set

$$C = cov\left(\vec{N}\right)$$

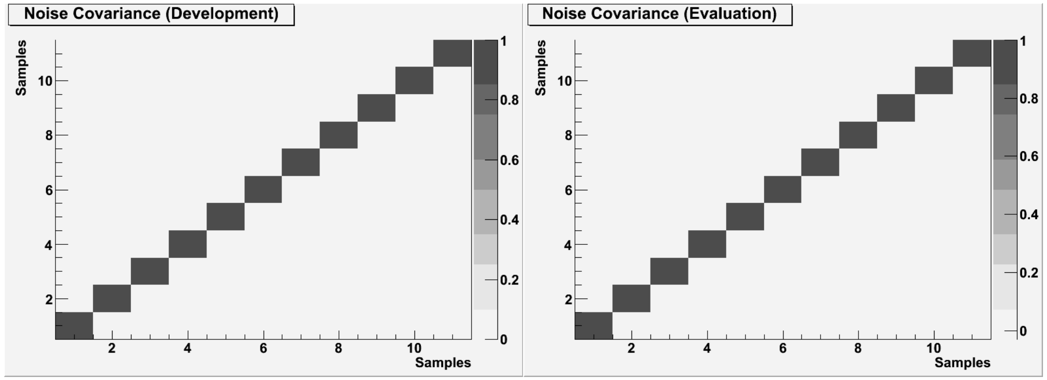
$$\left[E, D\right] = eig\left(C\right)$$

$$W = D^{-1/2} E^{T}$$

Before whitening

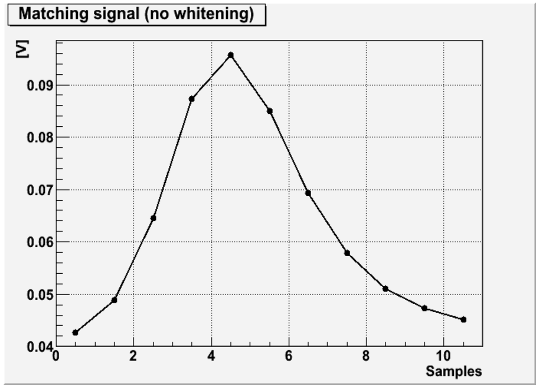


After whitening

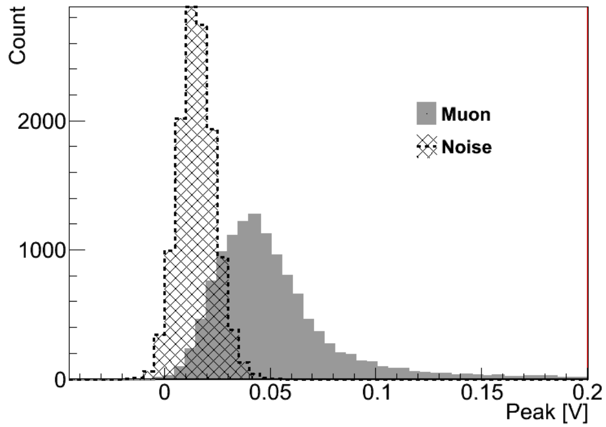


Matched Filter

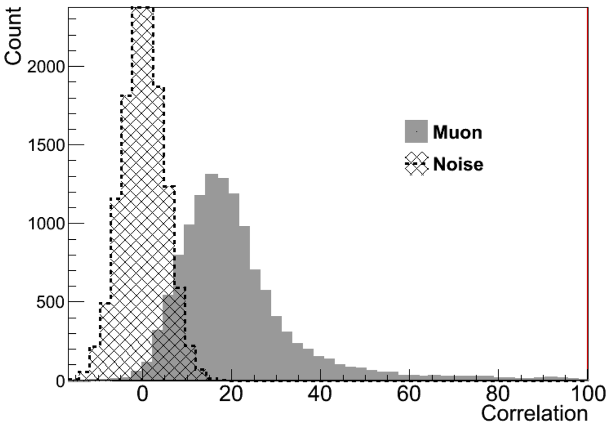
- Considering Gaussian noise
  - Independent after whitening stage
  - Correlation between noise and muon signals should be null



Threshold discriminator

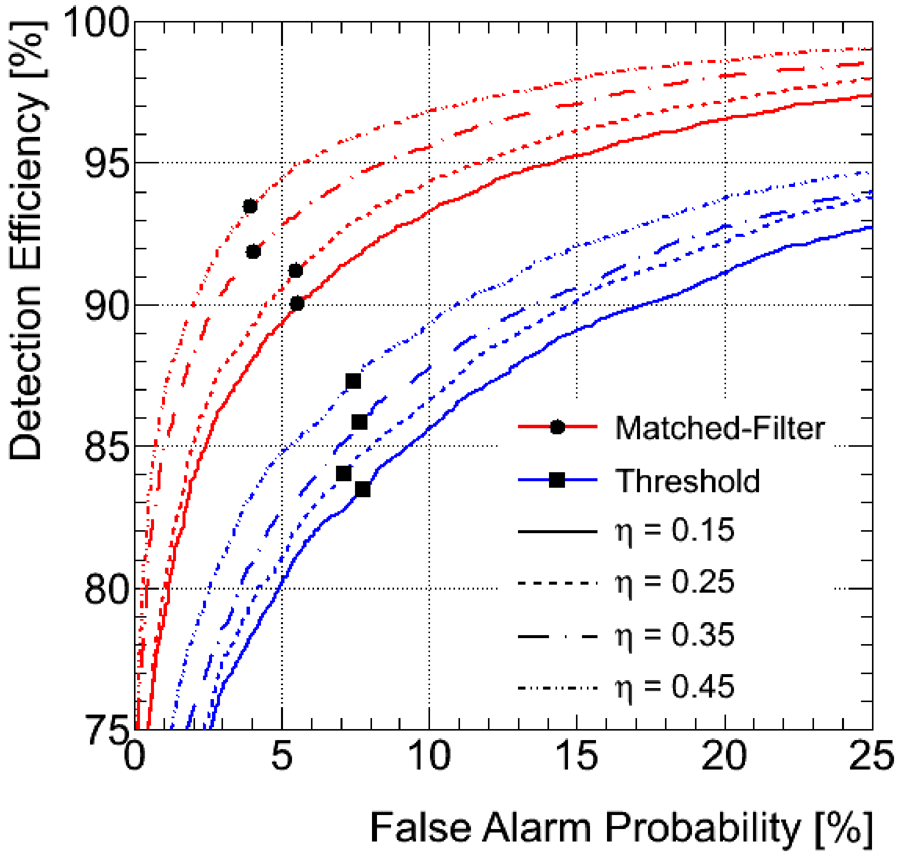


Matched filter discriminator



Matched Filter (2)

- Receiver Operating Characteristics
  - Matched filter shows better results in all hitting directions
  - For 5 % false alarm, probability up to 94.5 % signal efficiency



Conclusions

- The ATLAS L1 Trigger system can combine RPC and Tile information for muon detection
- Tile calorimeter information can be used to assist triggering on muons
  - Summing both muon signals from the same cell increases SNR
- Noise contribution from the receiver summing circuit is negligible
- Matched filter performance
  - The proposed implementation, although simple, proved to be efficient
  - Near 10 p.p. improvement in muon detection for a fixed alarm of 10%, wrt threshold detection

Ongoing Analysis

- Matched filter design considering full stochasticity
  - Better representation for the noise at the receiver input
  - Make use of Independent Component Analysis
    - *Access high-order statistics*
  - Simulate the Muon Spectrometer integration
  - Performance wrt hybrid (analogue + FPGA implementation)