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A Firmware-oriented Trigger Algorithm for CMS Drift Tubes in HL-LHC

A full replacement of the muon trigger system in the CMS (Compact Muon Solenoid) detector is envisaged for operating at the maximum instantaneous luminosities expected in HL-LHC (High Luminosity Large Hadron Collider) of about 5-7.5x10^{34} $cm^{-2}s^{-1}$. Under this scenario, the new on detector electronics that is being designed for the DT (Drift Tubes) detector will forward all the chamber information at its maximum time resolution. A new trigger system based on the highest performing FPGAs is being designed and will be capable of providing precise muon reconstruction and Bunch Crossing identification. An algorithm easily portable to FPGA architecture has been designed to implement the trigger primitive generation from the DT detector. This algorithm has to reconstruct muon segments from single wire DT hits which, for a given BX, come with a spread of 400 ns due to the drift time in the cell. This algorithm provides the maximum resolution achievable by the DT chambers, bringing the hardware system closer to the offline performance capabilities. The results of the simulation and of the first implementations in the new electronics test bench are shown.

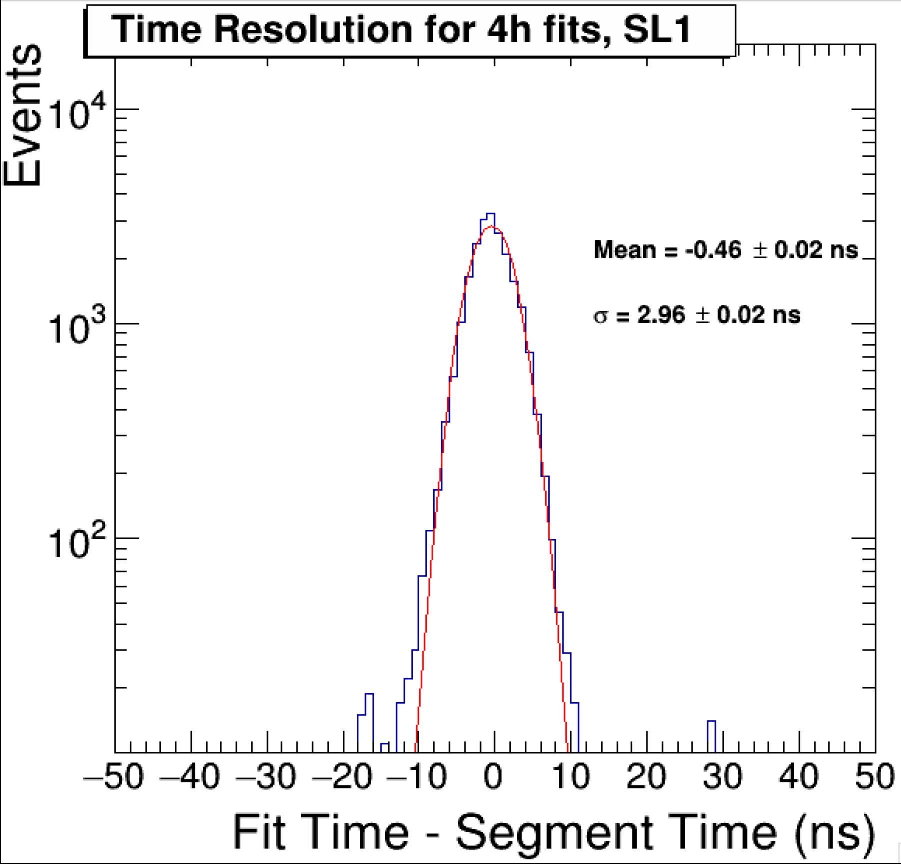
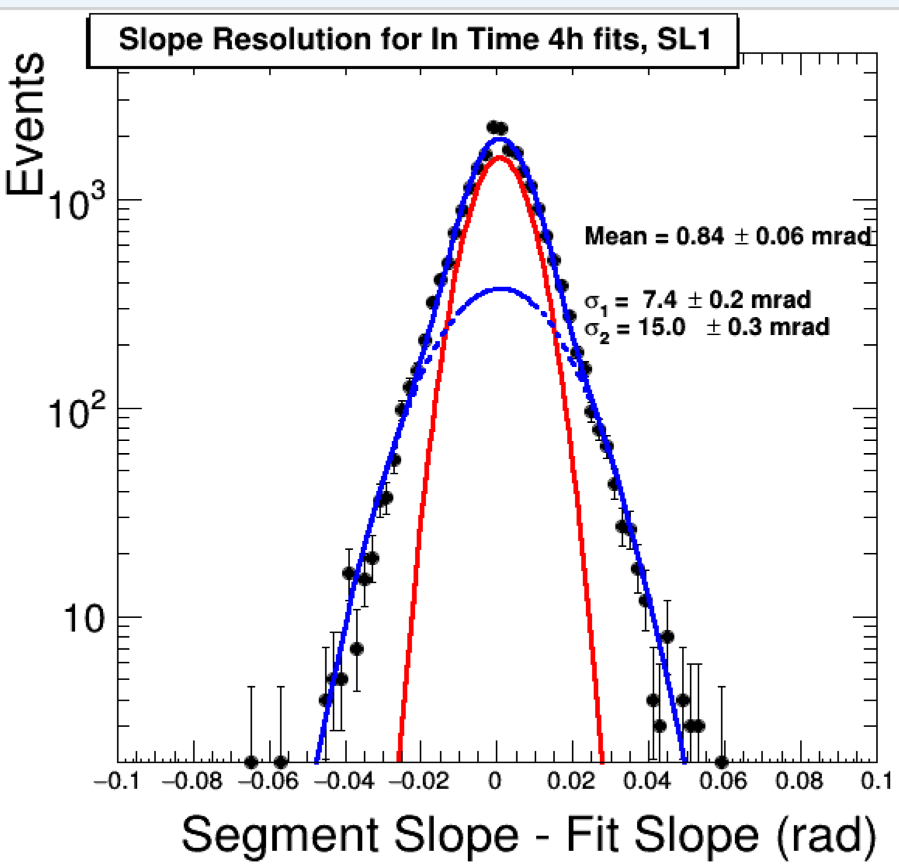
Description of the algorithm: Analytical Method

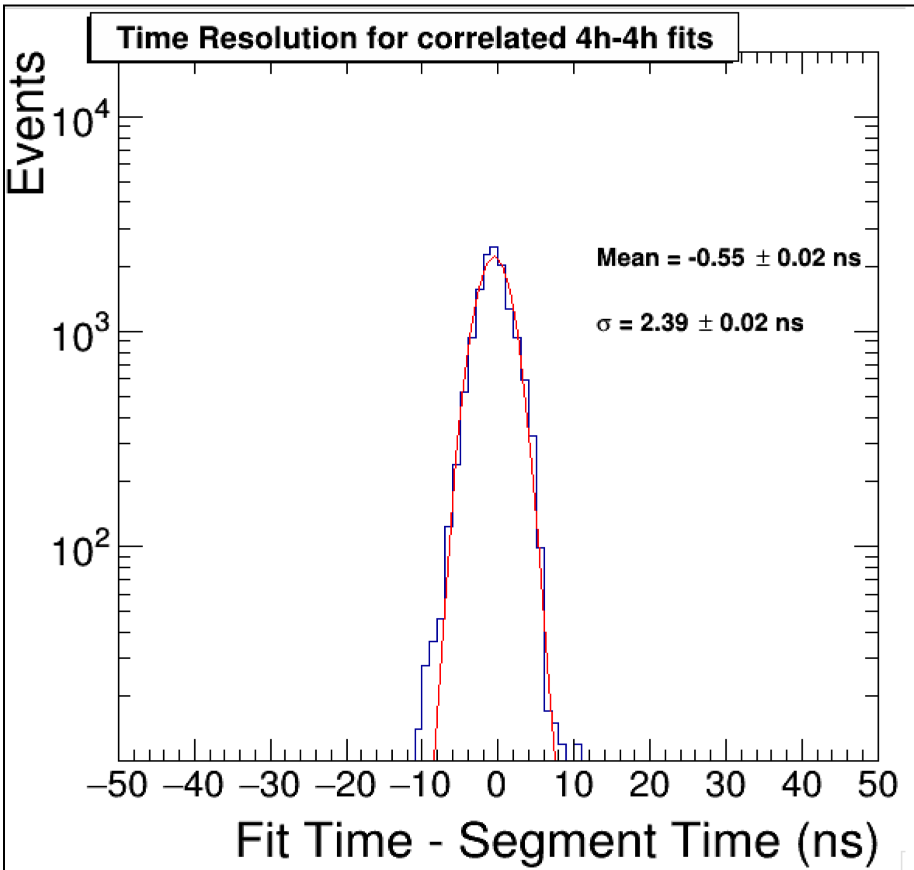
The input information is the wire position of the hit cell and the hit time from the start of the LHC orbit. From this, and assuming a given laterality, the hit position can be reconstructed. For a given hypothesis of muon trajectory within a super-layer, which is a straight line, using information from 3 cells allows to solve for the collision time, as the dependence on track slope is factored out. In this way one can identify the bunch crossing (BX) of the corresponding proton-proton interaction where the muon was produced. In practice a selection is made of patterns of 4 tubes and their sub-patterns of 3 tubes over 10 cells at a time, containing all physical trajectories in the given super layer. For cases with 4 hits (one per layer), time is computed from each triplet and then combined in an arithmetic mean. Once the collision time is known, the track parameters are computed using exact formulas from least squares method (chi2-minimisation). For 3 hits all hit laterality assumptions providing physical solutions are considered as candidates. For 4 hits select a unique final candidate, the one with minimum chi2. For muons with fits of 4 hits or 3 hits both in super-layer 1 (SL1) and and super-layer 3 (SL3), the information from both fits can be correlated if the corresponding segment times are within a window of +/- 25 ns. If a match is found the candidate trigger primitive parameters are re-defined as follows: the new time is the mean of the per super layer fits times, the new position is the mean of the superlayer fits positions, and the new slope is computed from the difference in fit positions in SL3 and SL1 divided by distance between the two r-phi super layers. If no match found, all per-superlayer candidates are kept. This algorithm has been implemented in CMS software (CMSSW) as an emulator for the firmware implementation in FPGA.

Definitions: INTRINSIC performance and EMULATOR performance

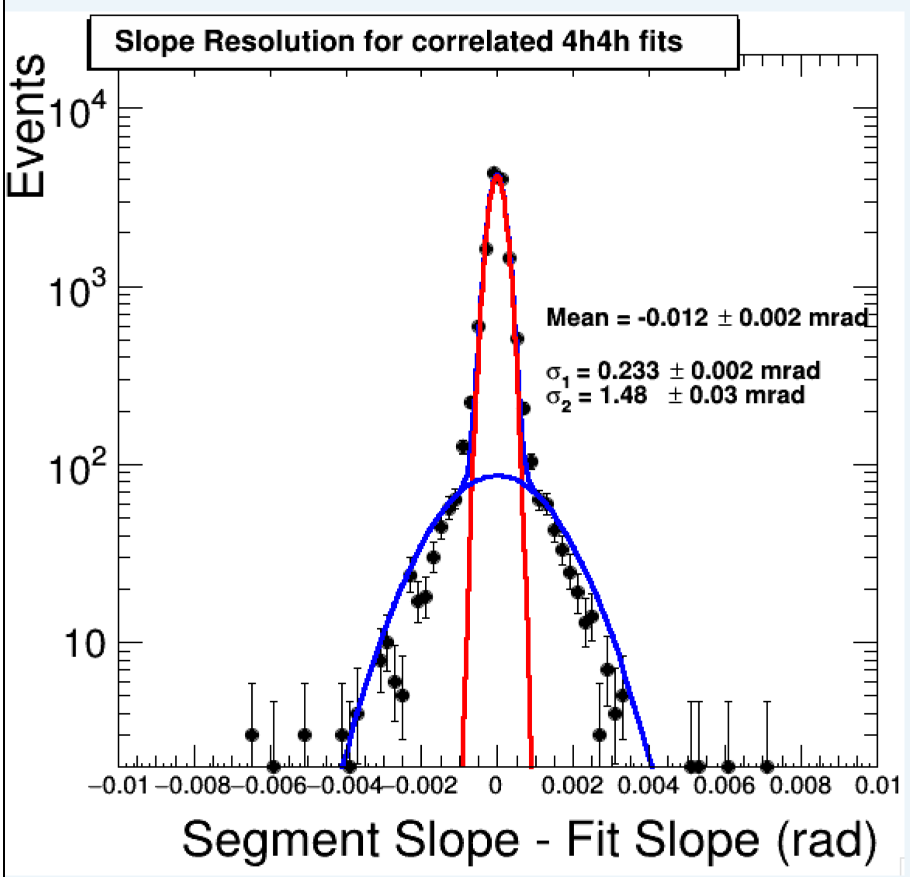
- INTRINSIC PERFORMANCE: As first step, we have evaluated the performance for obtaining the track parameters with a least square fitting method (chi2 minimisation) for all variables, including the time for fits with 4 hits, in clean conditions, i.e. taking as input the calibrated times of only those hits associated to offline segments. This allows evaluation of intrinsic performance of a exact solution for obtaining all the track parameters
- EMULATOR PERFORMANCE: The trigger primitive is reconstructed with the Analytical Method as implemented in the Emulator, including the beforehand described full grouping and pattern recognition. In case more than one trigger primitive is generated, the one closest to offline segment in x coordinate has been selected for performance studies

List of Plots

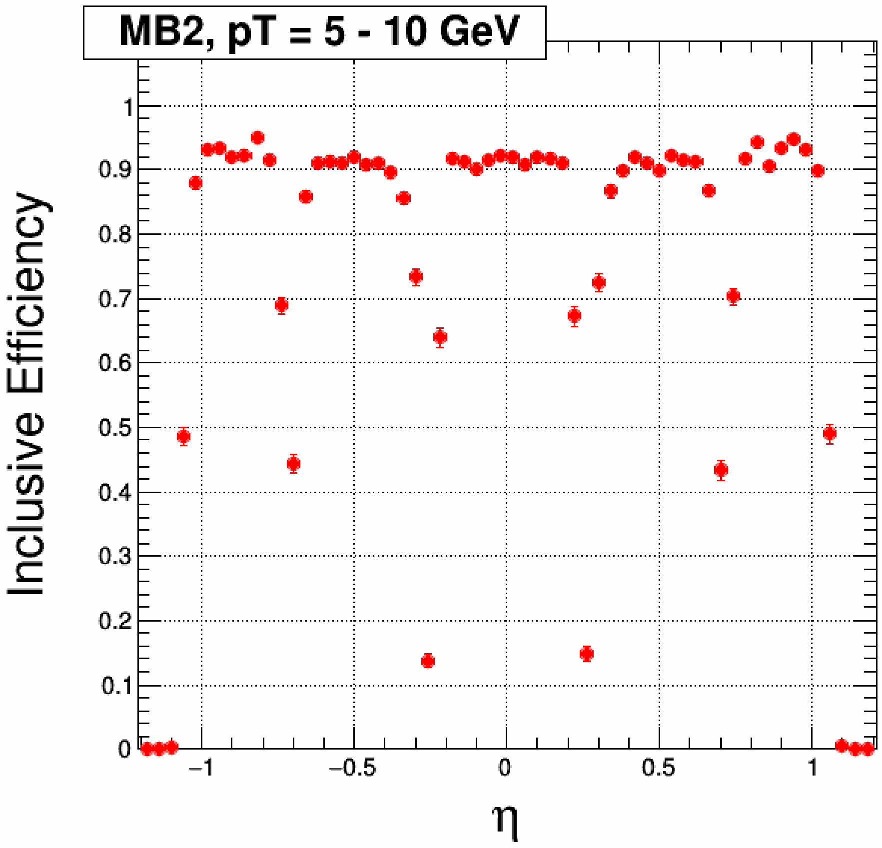
Figure	Caption
	**INTRINSIC performance:** Difference between trigger primitive reconstructed time and offline segment reconstructed time (time resolution), fitted to a gaussian, for primitives with 4 hits in super layer 1.The trigger primitive is reconstructed from hits associated to the offline segment in muons decays of Z bosons in a 2017 sample. All track parameters, including time, are obtained from a least square fitting method. All DT chambers are included. The sigma of the gaussian fit is ~3 ns. Note: the offline segment is reconstructed from hits in more than one superlayer, it is therefore a good proxy for true value of considered variables, and small correlation is expected in this difference.
	**INTRINSIC performance:** Difference between trigger primitive reconstructed slope and offline segment reconstructed slope (slope resolution), fitted to two gaussians, for primitives with 4 hits in super layer 1. The trigger primitive is reconstructed from hits associated to the offline segment in muons decays of Z bosons in a 2017 sample. All track parameters, including time, are obtained from a least square fitting method. All DT chambers are included. The sigma of the narrow gaussian fit is ~7 mrad. Note: the offline segment is reconstructed from hits in more than one superlayer, it is therefore a good proxy for true value of considered variables, and small correlation is expected in this difference.



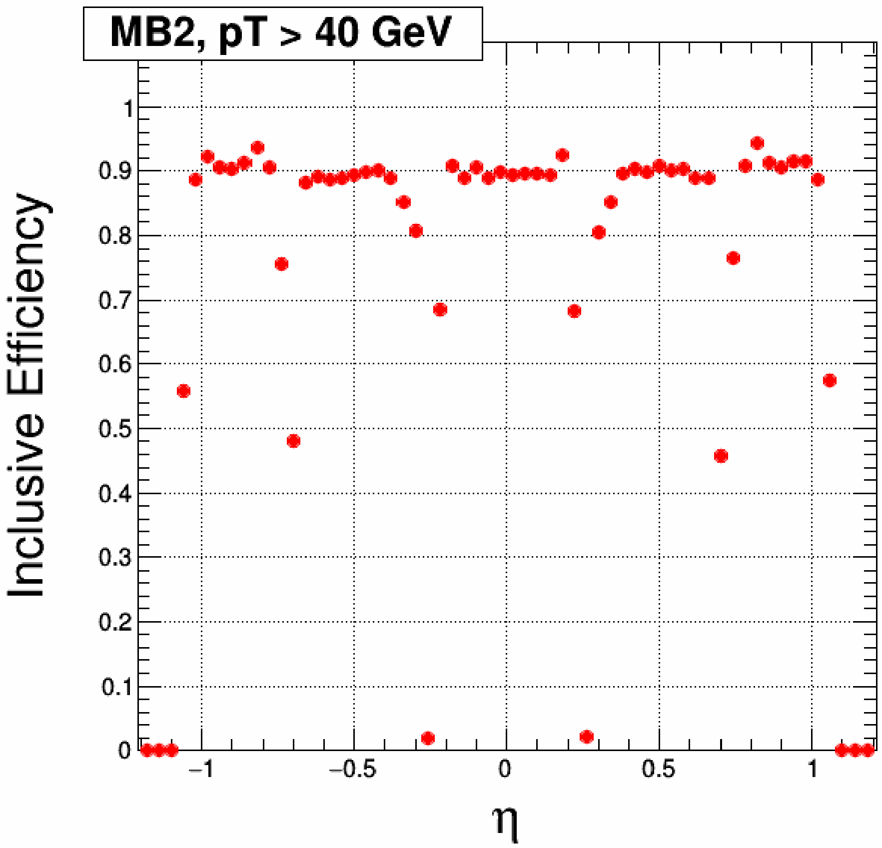
INTRINSIC performance: Difference between trigger primitive reconstructed time and offline segment reconstructed time (time resolution), fitted to a gaussian, for correlated primitives with 4 hits in super layer 1 and 4 hits in super layer 3. The trigger primitive is reconstructed from hits associated to offline segment in muons decays of Z bosons in a 2017 sample. All track parameters, including time, are obtained from a least square fitting method. All DT chambers are included. The sigma of the gaussian fit is <3 ns. Note: relevant correlations between fit results and variables obtained from offline segment are possible



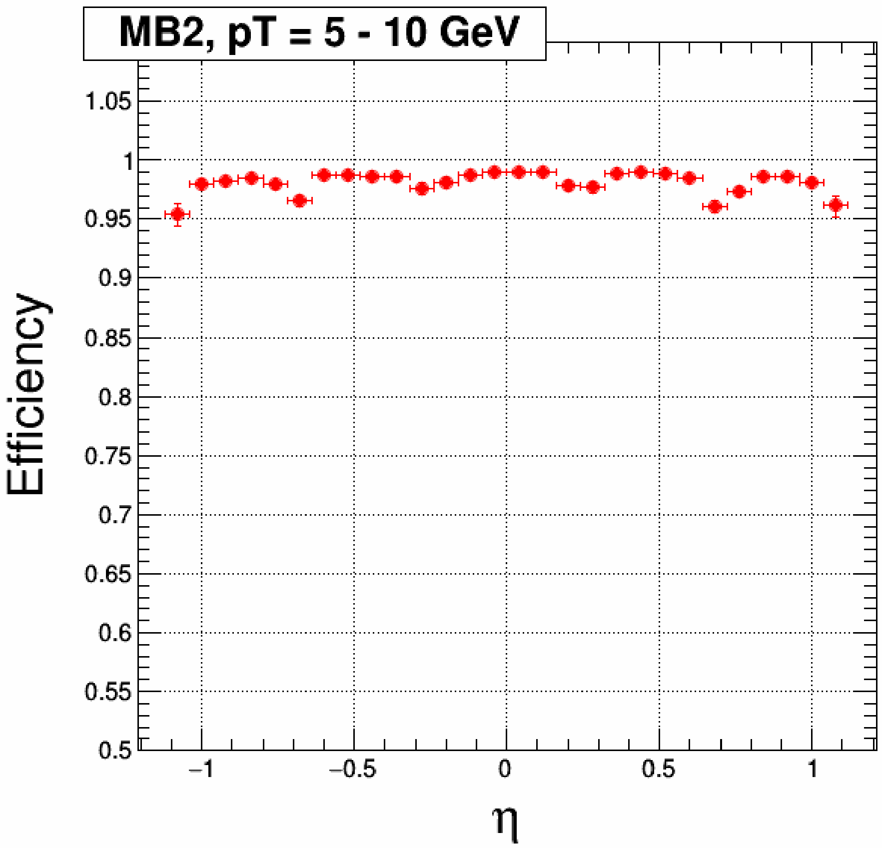
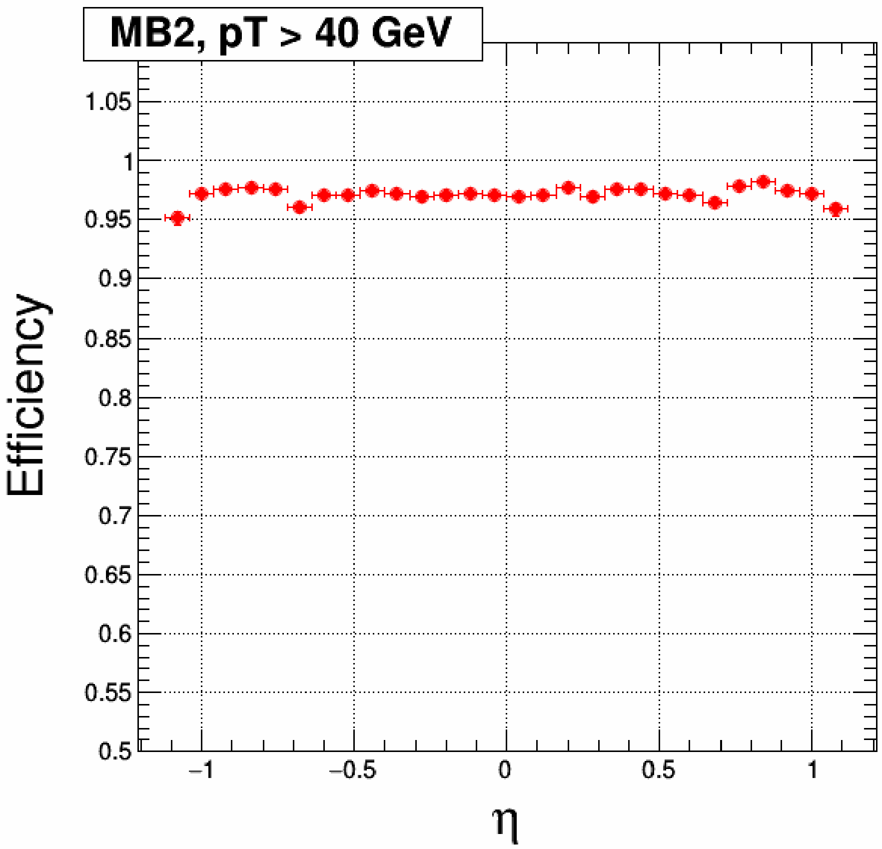
INTRINSIC performance: Difference between trigger primitive reconstructed slope and offline segment reconstructed slope (slope resolution), fitted to a gaussian, for correlated primitives with 4 hits in super layer 1 and 4 hits in super layer 3. The trigger primitive is reconstructed from hits associated to offline segment in muons decays of Z bosons in a 2017 sample. All track parameters, including time, are obtained from a least square fitting method. All DT chambers are included. The sigma of the narrow gaussian fit is < 1 mrad. The big improvement with respect to fits in a given super layer comes from the increased lever arm given by the distance between SL1 and SL3. Note: relevant correlations between fit results and variables obtained from offline are segment possible

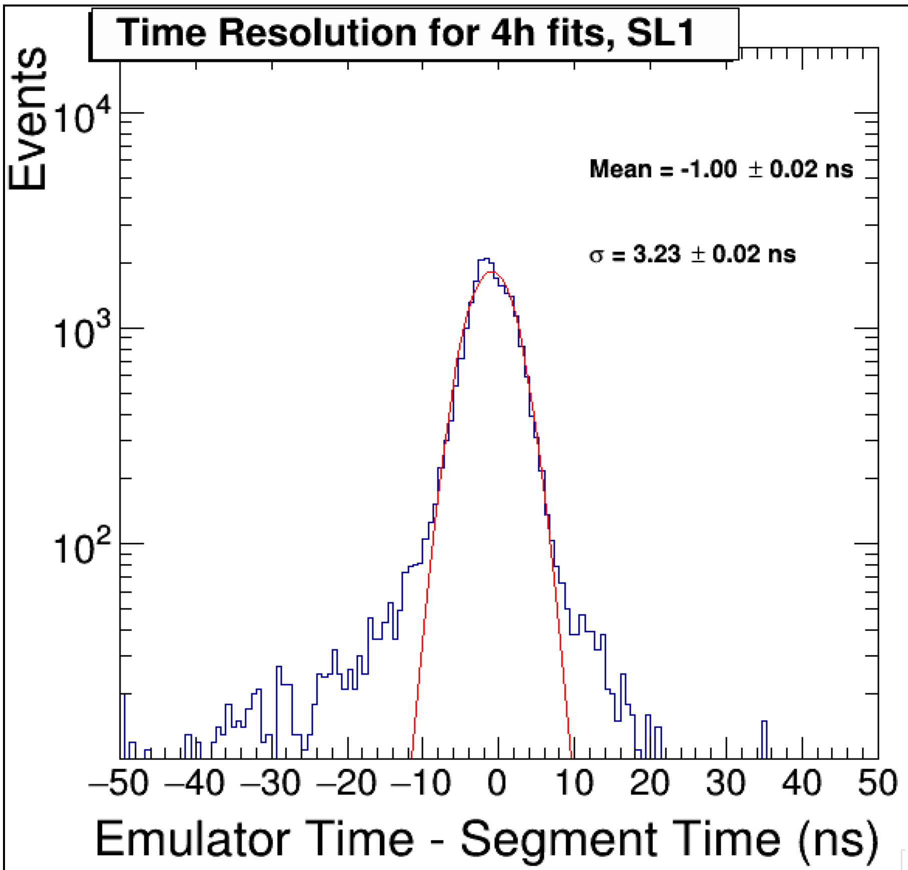


INTRINSIC performance: Inclusive Trigger Primitive efficiency in Station 2, computed on Monte Carlo muon gun sample with zero pile up, for muons with pt =5-10 GeV. The trigger primitive is reconstructed from hits associated to the offline segment. All track parameters, including time, are obtained from a least square fitting method. The denominator includes all muons passing a set of standard quality cuts crossing a given DT chamber. The numerator counts when there is at least one fit of any quality (ie, fits with either 3 hits or 4 hits) in SL1 OR SL3 in the correct bunch crossing (BX=0 for simulation) in that given chamber. The time from the correlated fit is taken when available. Measured efficiencies are high, reflecting very good time resolution in all chambers. Dips are related to acceptance

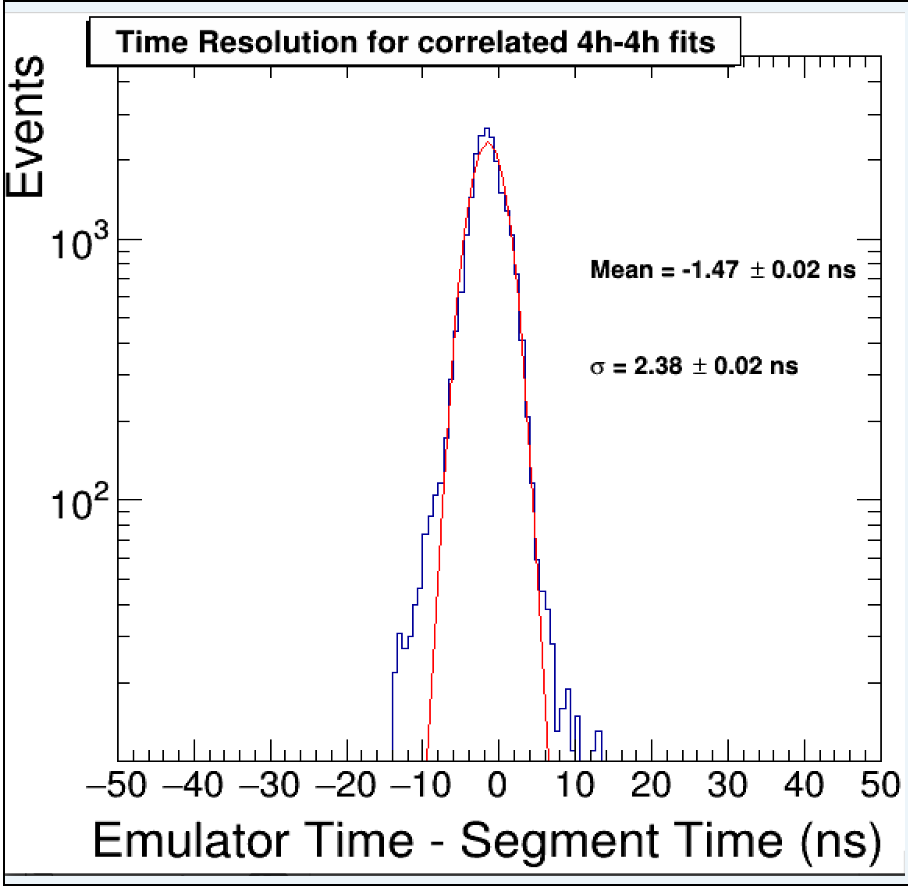


INTRINSIC performance: Inclusive Trigger Primitive efficiency in Station 2, computed on Monte Carlo muon gun sample with zero pile up, for muons with pt > 40 GeV. The trigger primitive is reconstructed from hits associated to the offline segment. All track parameters, including time, are obtained from a least square fitting method. The denominator includes all muons passing a set of standard quality cuts crossing a given DT chamber. The numerator counts when there is at least one fit of any quality (ie, fits with either 3 hits or 4 hits) in SL1 OR SL3 in the correct bunch crossing (BX=0 for simulation) in that given chamber. The time from the correlated fit is taken when available. Measured efficiencies are high, reflecting very good

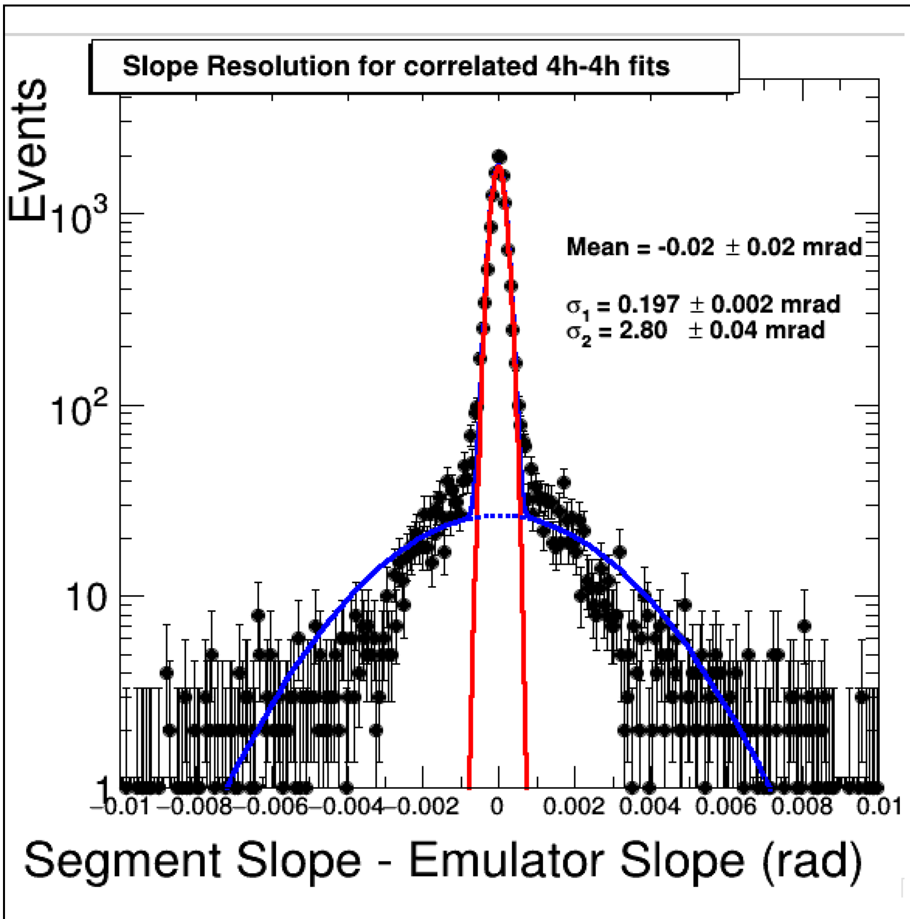
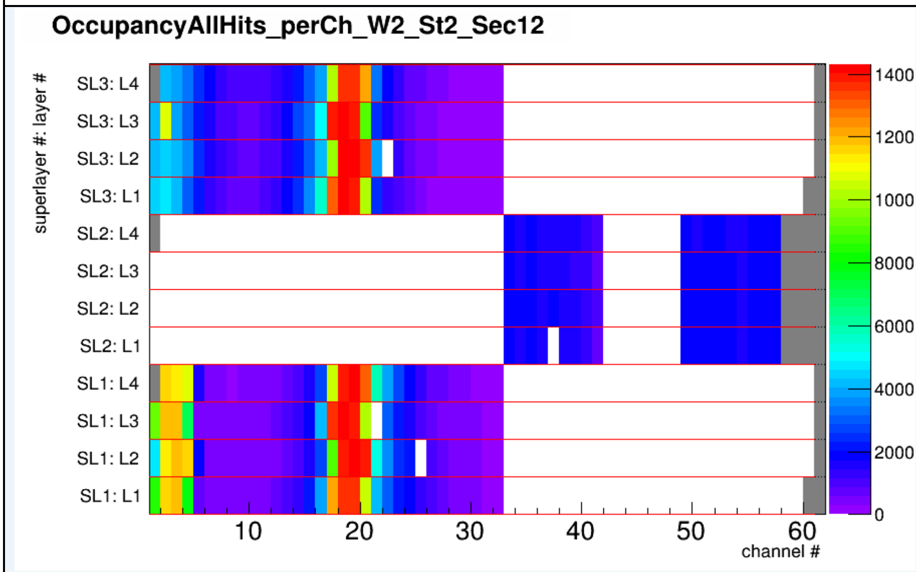
	time resolution in all chambers. Dips are related to acceptance
 	**INTRINSIC performance:** Trigger Primitive efficiency in Station 2, computed on Monte Carlo muon gun sample with zero pile up, for muons with pt =5-10 GeV.The trigger primitive is reconstructed from hits associated to offline segment. Track parameters are obtained from a least square fitting method. The denominator include all muons passing a set of standard quality cuts and with reconstructed segments with at least 4 associated hits in that chamber. The numerator counts when there is at least one fit of any quality (ie, fits with either 3 hits or 4 hits) in SL1 OR SL3 in the correct bunch crossinig (BX=0 for simulation). Measured efficiencies are high, reflecting very good time resolution in all chambers.
 	**INTRINSIC performance:** Trigger Primitive efficiency in Station 2, computed on Monte Carlo muon gun sample with zero pile up, for muons with pt 40 > GeV. The trigger primitive is reconstructed from hits associated to offline segment. Track parameters are obtained from a least square fitting method. The denominator include all muons passing a set of standard quality cuts and with reconstructed segments with at least 4 associated hits in that chamber. The numerator counts when there is at least one fit of any quality (ie, fits with either 3 hits or 4 hits) in SL1 OR SL3 in the correct bunch crossinig (BX=0 for simulation). Measured efficiencies are high, reflecting very good time resolution in all chambers.



EMULATOR performance: Difference between trigger primitive reconstructed time and offline segment reconstructed time (time resolution), fitted to a gaussian, for primitives with 4 hits in super layer 1. The trigger primitive is reconstructed with the Analytical Method as implemented in the Emulator, including full grouping and pattern recognition, for muons coming from Z bosons decays in a 2016 sample. All DT chambers are included. The sigma of the gaussian fit is ~3 ns. Note: the offline segment is reconstructed from hits in more than one superlayer, it is therefore a good proxy for true value of considered variables, and small correlation is expected in this difference.



EMULATOR performance: Difference between trigger primitive reconstructed time and offline segment reconstructed time (time resolution), fitted to a gaussian, for correlated primitives with 4 hits in super layer 1 and 4 hits in super layer 3. The trigger primitive is reconstructed with the Analytical Method as implemented in the Emulator, including full grouping and pattern recognition, for muons coming from Z bosons decays in a 2016 sample. All DT chambers are included. The sigma of the gaussian fit is <3 ns. The reduction of tails with respect performance at super-layer level is only is due to the correlation. Note: relevant correlations between fit results and variables obtained from offline segment are possible

	**EMULATOR performance:** Difference between trigger primitive reconstructed slope and offline segment reconstructed slope (slope resolution), fitted to two gaussians, for correlated primitives with 4 hits in super layer 1 and 4 hits in super layer 3. The trigger primitive is reconstructed with the Analytical Method as implemented in the Emulator (including full grouping of DT hits and pattern recognition), for muons coming from Z bosons decays in a 2016 sample. All DT chambers are included. The sigma of the narrow gaussian fit is < 1 mrad, in agreement with corresponding results on intrinsic performance. Note: relevant correlations between fit results and variables obtained from offline segment are possible
	In a spare DT chamber signals have been splitted into the two different electronics chains such that the legacy electronics chain and the upgrade chain register the same (cosmic muon) event. The plot shows the occupancy of muon hits recorded in the legacy chain, and triggered by the phase 2 electronics chain, as shown by the DT Data Quality Monitor application. In each superlayer half of the cells signals are split to the phase 2 chain and readout by the legacy electronics: cells 1-30 in the phi superlayer and cells 31-57 in the theta superlayer. The front-end signals of cells 1-4 of SL1 and of cells 17-20 of SL1 and SL3 are used by the phase2 electronics to produce trigger primitives. The plot shows the occupancy of hits readout by the legacy electronics: the distribution shows that the new trigger is working as expected.

	For triggers from channels 1-4 in super layer 1, hits are found on super layer3, but with low efficiency due to rough timing. Note: Super layer 2 was not fully commissioned at the time of the test

-- SilviaGoyLopez - 2019-04-08

This topic: Sandbox > AnalyticalMethodDTTriggerPhase2
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