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Analytical Method (AM) for DT Trigger Primitive Generation in Phase2: September 2021 results

See also: **CMS DP-2021/028**⧉ and **CMS DP-2021/028**⧉

Previous results have been reported here

INTRODUCTION

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 $5\text{-}7.5\text{x}10^{34}$ $cm^{-2}s^{-1}$. 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 TP (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.

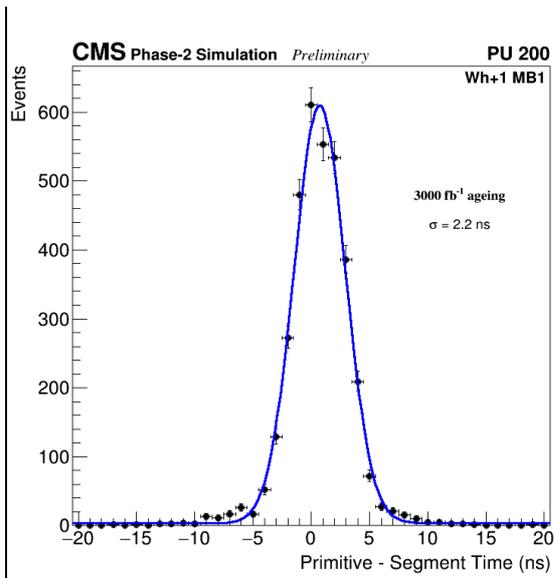## Description of the algorithm: Analytical Method

The input information is the wire position of the hit cell and the hit time from the start of the LHC orbit. Since any hit can be left or right with respect to the wire position, an assumption needs to be made about its laterality. For a given laterality assumption and using the above information, 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 and 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. In a final step information from RPCs can be added to define   super-primitives , with corrected time measurement. Note that results presented here do not use RPC information. This algorithm has been implemented in CMS software (CMSSW) as an emulator for the firmware implementation in FPGA. In addition, a quality flag is defined for the trigger primitives as follows:Quality 1 refers to TPs made of a fit of 3 hits in a single SL. Quality 2 to TPs made of a fit of 3 hits in a single SL and confirmed by 2 hits in the other SL. Quality 3 to TPs made of a fit of 4 hits in a single SL. Quality 4 to TPs made of a fit of 4 hits in a single SL and confirmed by 2 hits in the other SL. Qualities 6,7 and 8 refer to correlated primitives, made respectively of fits of 3 hits in one SL and fits of 3 hits in the other, of fits of 3 hits in one SL and fits of 4 hits in the other and of fits of 4 hits in both SLs.

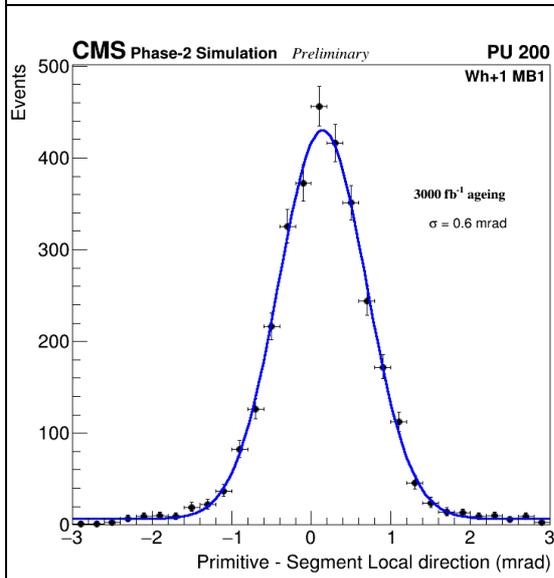| Quality	1	2	3	4	6	7	8
Description	3-hit track	3+2 hits track	4 hit track	4+2 hits track	3+3 hits track	4+3 hits track	4+4 hits track

Efficiency and resolution studies

Trigger Primitive efficiency and resolutions are evaluated in a privately simulated sample of 3700 events with 8 muons/event, using Phase-2 conditions. The <pile-up> is of 200 collisions/BX, including the most up-to-date recipe for neutron simulation, which is superimposed in a [-16,+16] BX to the signal of 4 muon pairs per event range with flat pT in the range [20,200] GeV and within | |<1.2. The sample is processed with and without assuming the end of phase-2 (3 ab-1) ageing/failure scenario. In particular the most up-to-date scenario for ageing and failures described in this Twiki is considered. When computing difference of TP fit results with respect to offline segments, relevant correlations between TP fit results and variables obtained from offline segment are possible due to sharing of hits

Figure	Caption
	Efficiency without ageing: Muon barrel trigger primitive efficiency for triggering in the right bunch crossing, computed in rings defined by DT chambers with same wheel and station (MB). Efficiency is computed with respect to local reconstructed segments geometrically matched with generator-level muons with pT> 20 GeV. Segments are required to have at least 4 hits in R-𝜑, to have a theta component (in MB1/2/3) with 4 hits, and their crossing time (t0seg) is requested to be in the [-15,15] ns range. No ageing is considered.
	Efficiency with ageing: Muon barrel trigger primitive efficiency for triggering in the right bunch crossing, computed in rings defined by DT chambers with same wheel and station (MB). Efficiency is computed with respect to local reconstructed segments geometrically matched with generator-level muons with pT> 20 GeV. Segments are required to have at least 4 hits in R-𝜑, to have a theta component (in MB1/2/3) with 4 hits, and their crossing time (t0seg) is requested to be in the [-15,15] ns range. End of phase2 ageing scenario is applied to the hits forming the trigger primitives. No ageing is applied to hits forming the segments considered for the efficiency computation. As expected, the drop in efficiency is higher for the chambers that are more affected by ageing
	Time Resolution: Time resolution with respect to offline segments, for correlated TPs in Wh+1 MB1. Ageing is applied to hits before TP formation. Resolution is computed with respect to local reconstructed segments geometrically matched with generator-level muons with pT> 20 GeV. Segments are required to have at least 4 hits in R-𝜑, and their crossing time (t0seg) is requested to be in the [-15,15] ns range. A Gaussian plus constant function is fitted. Note: relevant correlations

between TP fit results and variables obtained from offline segment are possible.

Local direction Resolution: Local direction resolution with respect to offline segments, for correlated TPs in Wh+1 MB1. Ageing is applied to hits before TP formation. Resolution is computed with respect to local reconstructed segments geometrically matched with generator-level muons with pT> 20 GeV. Segments are required to have at least 4 hits in R-𝜑, and their crossing time (t0seg) is requested to be in the [-15,15] ns range. A Gaussian plus constant function is fitted. Note: relevant correlations between TP fit results and variables obtained from offline segment are possible.
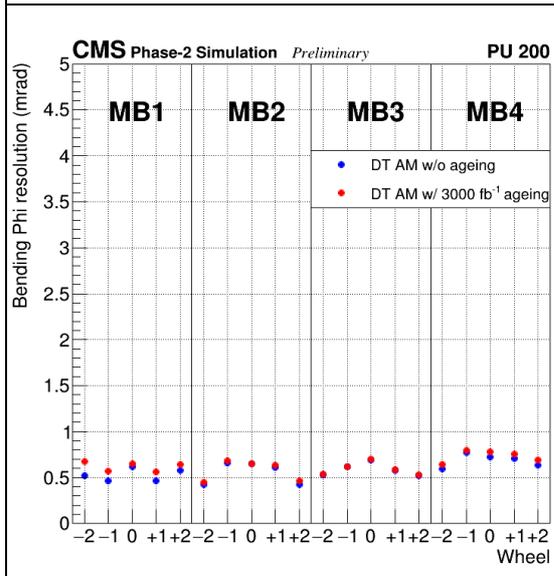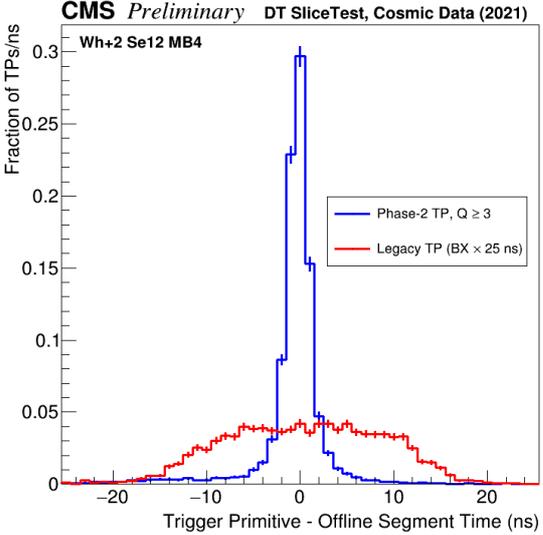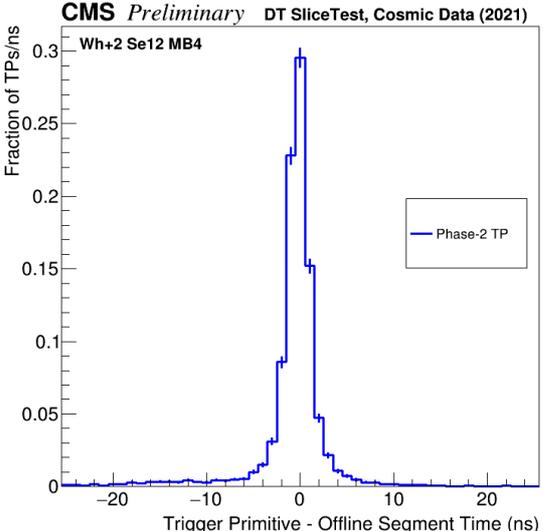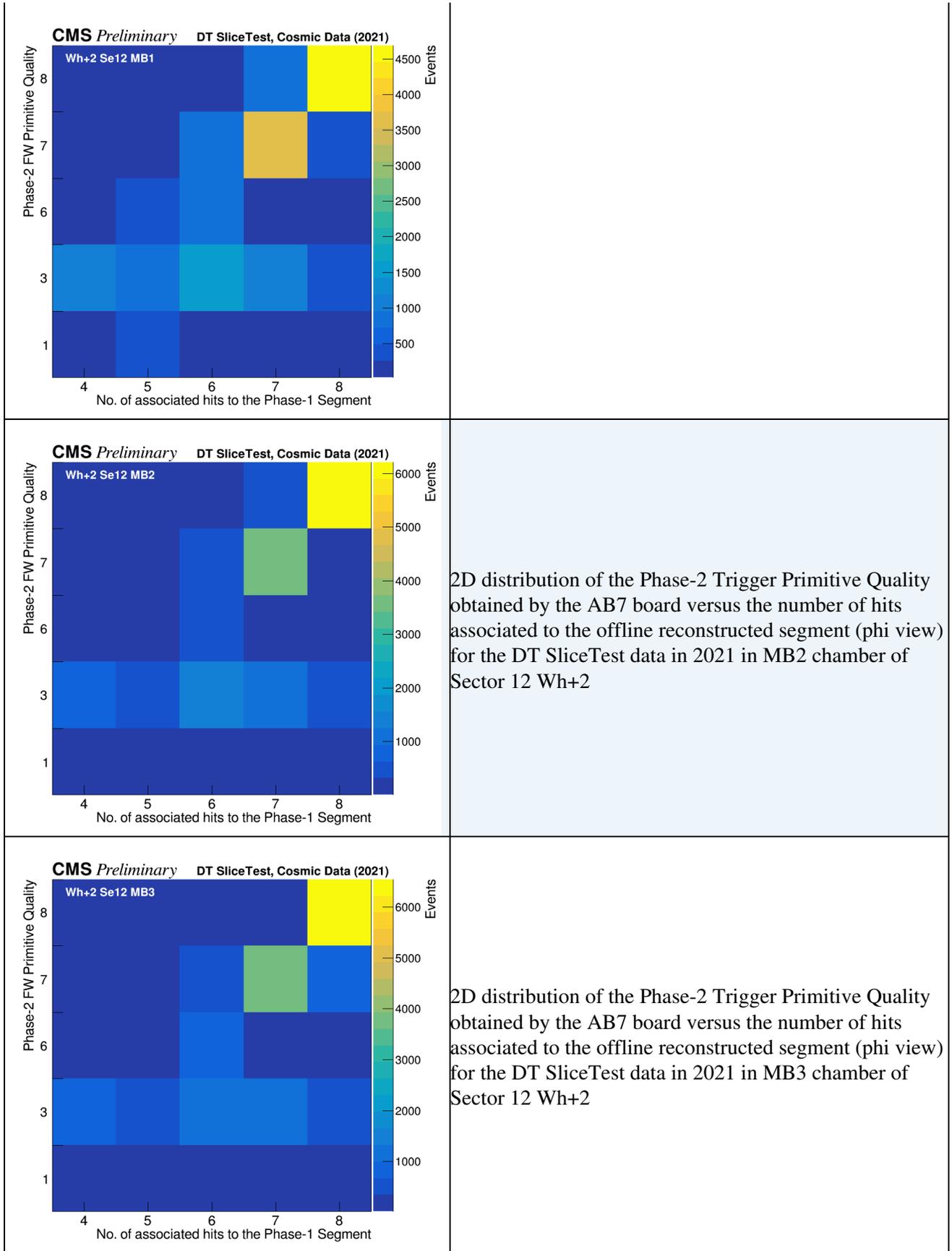
Global Direction Resolution Summary: Angular bending (direction) resolution, , with respect to offline segments, for all TP qualities, computed in rings defined by DT chambers with same wheel and station (MB). Two ageing scenarios are considered: no ageing and end of HL-LHC ageing applied to hits before TP formation. Resolution is computed with respect to local reconstructed segments geometrically matched with generator-level muons with pT> 20 GeV. Segments are required to have at least 4 hits in R-𝜑, and their crossing time (t0seg) is requested to be in the [-15,15] ns range.A Gaussian plus constant function is fitted. The width of the gaussian ( ) is reported in the plot.Note: relevant correlations between TP fit results and variables obtained from offline segment are possible
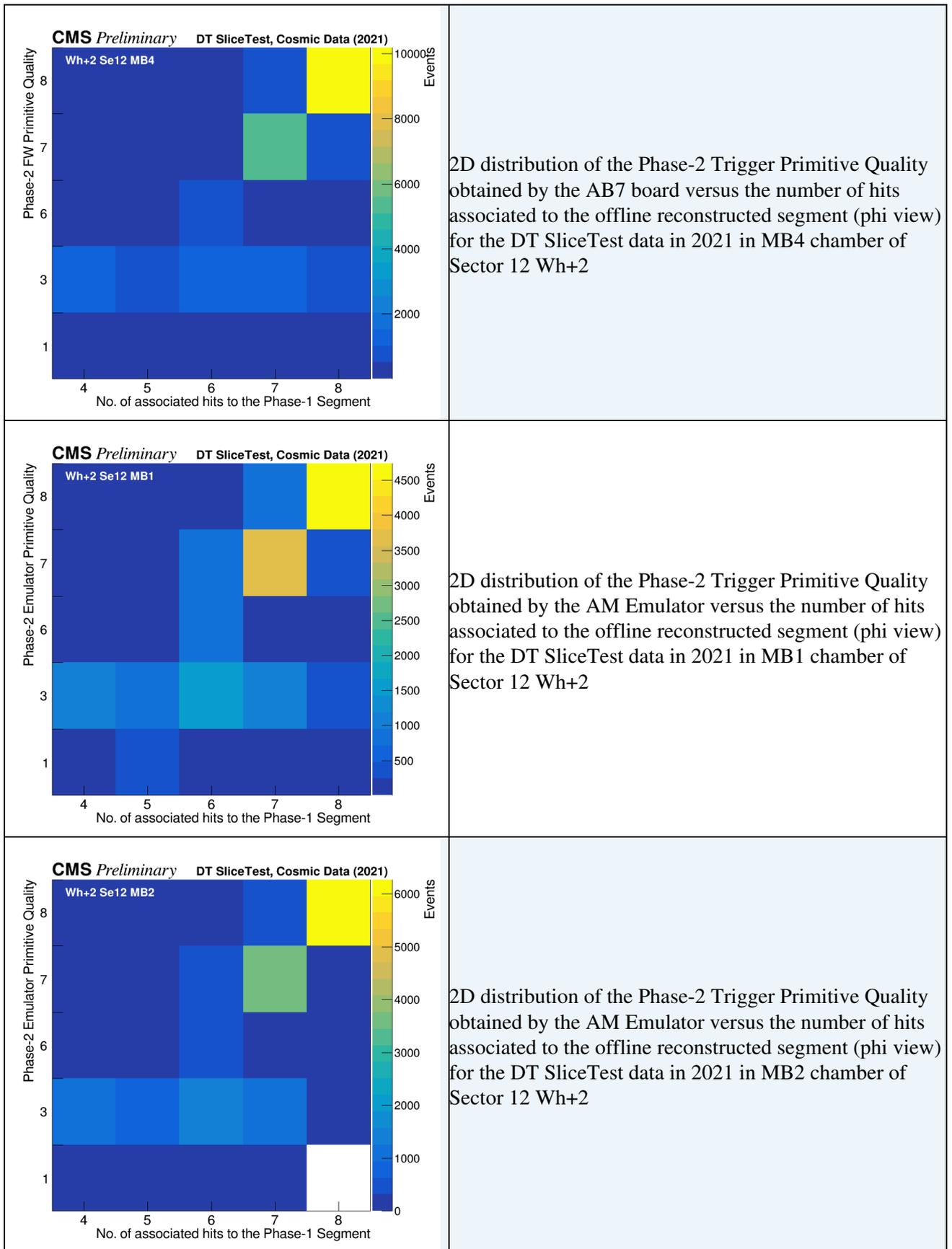
Slice Test results

During Long Shutdown 2 a complete exercise has been made to instrument one sector (wheel +2 sector 12) of the CMS detector with the HL-LHC DT electronics front-end and back-end prototypes. One of these backend

boards (the so-called AB7) runs the AM firmware. This way, both Phase 1 and Phase 2 electronics can be run inside the CMS infrastructure, and the AM firmware can be validated using real cosmic muons. Plots show results using the information extracted from Phase-2 primitives (obtained by the AB7 board or the AM emulator) or Phase-1 primitives obtained by the TwinMux board, for a cosmic muon sample collected in YB+2/Se12 with the SliceTest set up and triggered by opposite sector (6) in a global run with the Barrel Muon Track Finder (BMTF). Phase-1 segments are reconstructed offline from legacy hits and selected to have a |local dir|< 30°, at least 4 hits, and |t0| < 50 ns. Time calibration correction has been implemented in the TDC data used to produce the Phase2 trigger primitives. The implementation of the calibration improves results substantially with respect to the L1 TDR. Note: Confirmed   qualities 2 (3+2 hit tracks) and 4 (4+2 hit tracks) are not implemented in the AM Firmware at the moment. Therefore, primitives with those qualities will end up with qualities 1 (3 hit tracks) and 3 (4 hit tracks) respectively at the current firmware output. This happens in particular in the Slice Test set up.

Figure	Caption
	Difference between trigger primitive s time and the offline reconstructed segment time, for Phase-2 in blue and for Legacy trigger (red) in a cosmic muon sample collected in the DT SliceTest set up. For Phase-2 only primitives fitting at least 4-hits are considered (denoted as Q≥3 in the legend), in order to be compared with the Legacy system (requesting minimal H quality). For the Legacy system the trigger output time is in BX units (25 ns step). The red line shows the convolution of a flat distribution within the BX time interval of 25 ns with a 3-4 ns time resolution of the reconstructed segment. For Phase-2, the inherent online time resolution is of ns. The improved online time resolution in Phase-2 reflects in this particular sample (unbunched cosmic muons) as a lower fraction of triggers at a wrong bx, i.e. 12.5 ns away from the time the muon crossed the chamber
	Difference between Phase-2 trigger primitive s time and the offline reconstructed segment time, for a cosmic muon sample collected in the DT SliceTest set up. Considering every quality (3-hit primitives included). Showing only Phase-2 trigger primitives, as 3-hit trigger primitives are not included in the Phase-1 system.The inherent online time resolution is of the order of ns.
	2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AB7 board versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB1 chamber of Sector 12 Wh+2

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2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AB7 board versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB2 chamber of Sector 12 Wh+2

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AB7 board versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB3 chamber of Sector 12 Wh+2

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AB7 board versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB4 chamber of Sector 12 Wh+2

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AM Emulator versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB1 chamber of Sector 12 Wh+2

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AM Emulator versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB2 chamber of Sector 12 Wh+2

Slice Test results

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AM Emulator versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB3 chamber of Sector 12 Wh+2

2D distribution of the Phase-2 Trigger Primitive Quality obtained by the AM Emulator versus the number of hits associated to the offline reconstructed segment (phi view) for the DT SliceTest data in 2021 in MB4 chambers of Sector 12 Wh+2

Efficiency of finding a Phase-2 Trigger Primitive in any BX with respect to the t0 of the offline segment reconstructed out of hits detected by the Phase-1 system considering every primitive (red), primitives built with more than 4 hits (blue) and primitives with more than 6 hits, i.e. 3 or more hits per Superlayer (green) for the DT SliceTest data in 2021 in MB4 Sector 12 Wh+2. Selected segments are built with more than 4 hits and have an inclination in the radial coordinate smaller than 30°with respect to the direction perpendicular to the chamber. No geometrical matching between the offline segment and the Trigger Primitive is required.
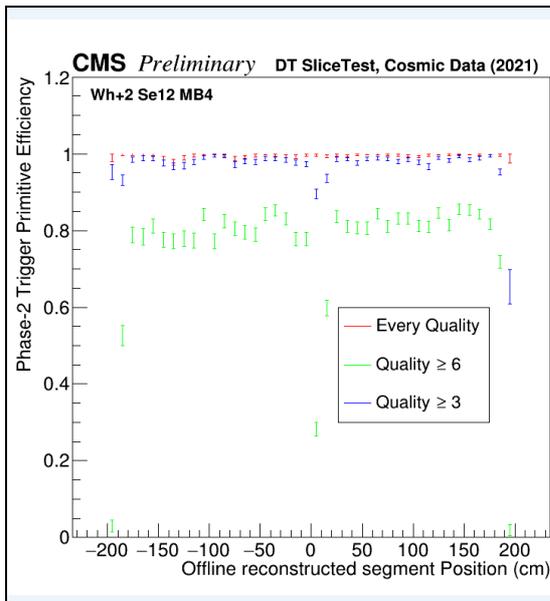
Efficiency of finding a Phase-2 Trigger Primitive in any BX with respect to the local position of the offline segment reconstructed out of hits detected by the Phase-1 system considering every primitive (red), primitives built with more than 4 hits (blue) and primitives with more than 6 hits, i.e. 3 or more hits per Superlayer (green) for the DT SliceTest data in 2021 in MB4 Sector 12 Wh+2. Selected segments are built with more than 4 hits and have an inclination in the radial coordinate smaller than 30°with respect to the direction perpendicular to the chamber. No geometrical matching between the offline segment and the Trigger Primitive is required. Since one AB7 prototype board only generates primitives from one half of the MB4 chamber, an efficiency drop is visible at the boundary (x=0) between the two regions due to edge effects. The final system will use only one board for the full chamber, so this effect will disappear.

-- SilviaGoyLopez - 2021-10-13

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