CMS RPC Upgrade Program

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Abstract

The LHC will be upgraded in several phases that will allow significant expansion of its physics program. The luminosity of the accelerator is expected to exceed $5 \times 10^{34}\ cm^{-2}s^{-1}$. In order to sustain the harsher conditions and to help maintaining good trigger efficiency and performance the Resistive Plate Chambers (RPC) system of the CMS experiment will be upgraded. The present RPC system would continue to operate, and it would be upgraded with new Link Boards system. In addition, the coverage of the RPC system would be increased up to pseudo rapidity of 2.4 by installing a new generation of improved RPCs (iRPCs). Their design and configuration are optimized to sustain higher rates and hence to survive the harsh background condition during HL-LHC operation. The iRPC are equipped with newly developed electronics designed to read out the detectors from both sides, allowing in this way a good spatial resolution along the strips O(cm). The status of the upgrade project is presented.

CMS RPC Upgrade

The CMS RPC upgrade for Phase-2 [1] comprehends **(1) the replacement of a the current Link System**, which connects the Front-End Boards (FEBs) to the trigger processors, by a new one, redesigned one from scratch and **(2) the extension of the pseudorapidity coverage of the RPC system**, by adding new chambers from $|\eta| = 1.9$ up to 2.4. Those new chamber will be assembled with a Improved Resistive Plate Chambers (iRPC) technology, which does the readout of signals in both ends of the strip, allowing a 2-dimensional hit reconstruction.

These upgrades would, in the expected high rate of the HL-LHC scenario:

- enhance the redundancy of the CMS Muon System;
- resolve ambiguities in the Endcap triggering;
- allow improvements of the RPC system to Trigger and reconstruction.

Figure 1 presents a quadrant of the CMS Muon system for the Phase-2 Upgrade. The locations of new forward muon detectors for the HL-LHC project are indicated in red

Figure 1: CMS Muon system for the Phase-2 Upgrade.

for Gas Electron Multiplier (GEM) stations (ME0, GE1/1, and GE2/1) and violet for improved RPC stations (RE3/1 and RE4/1).
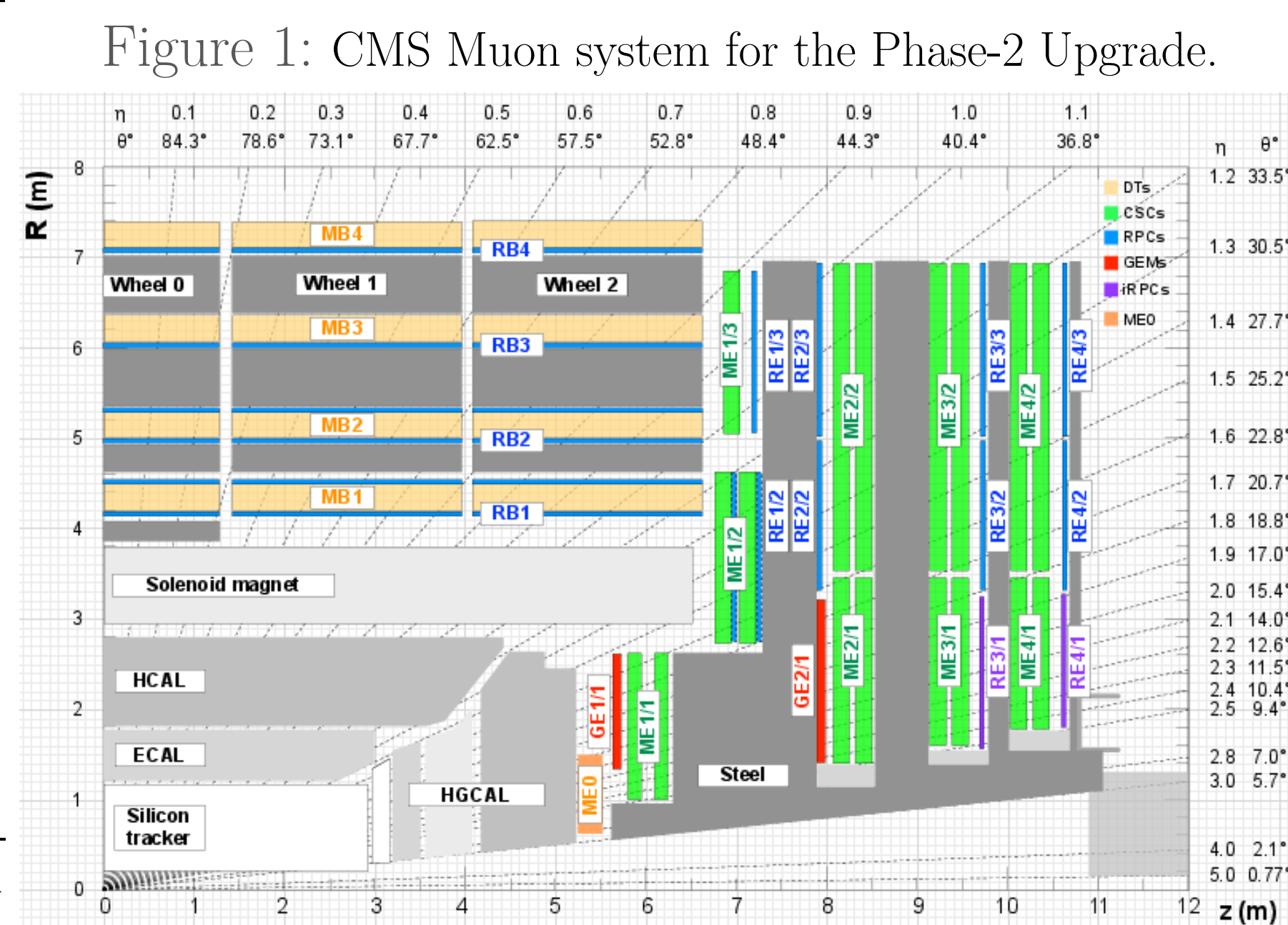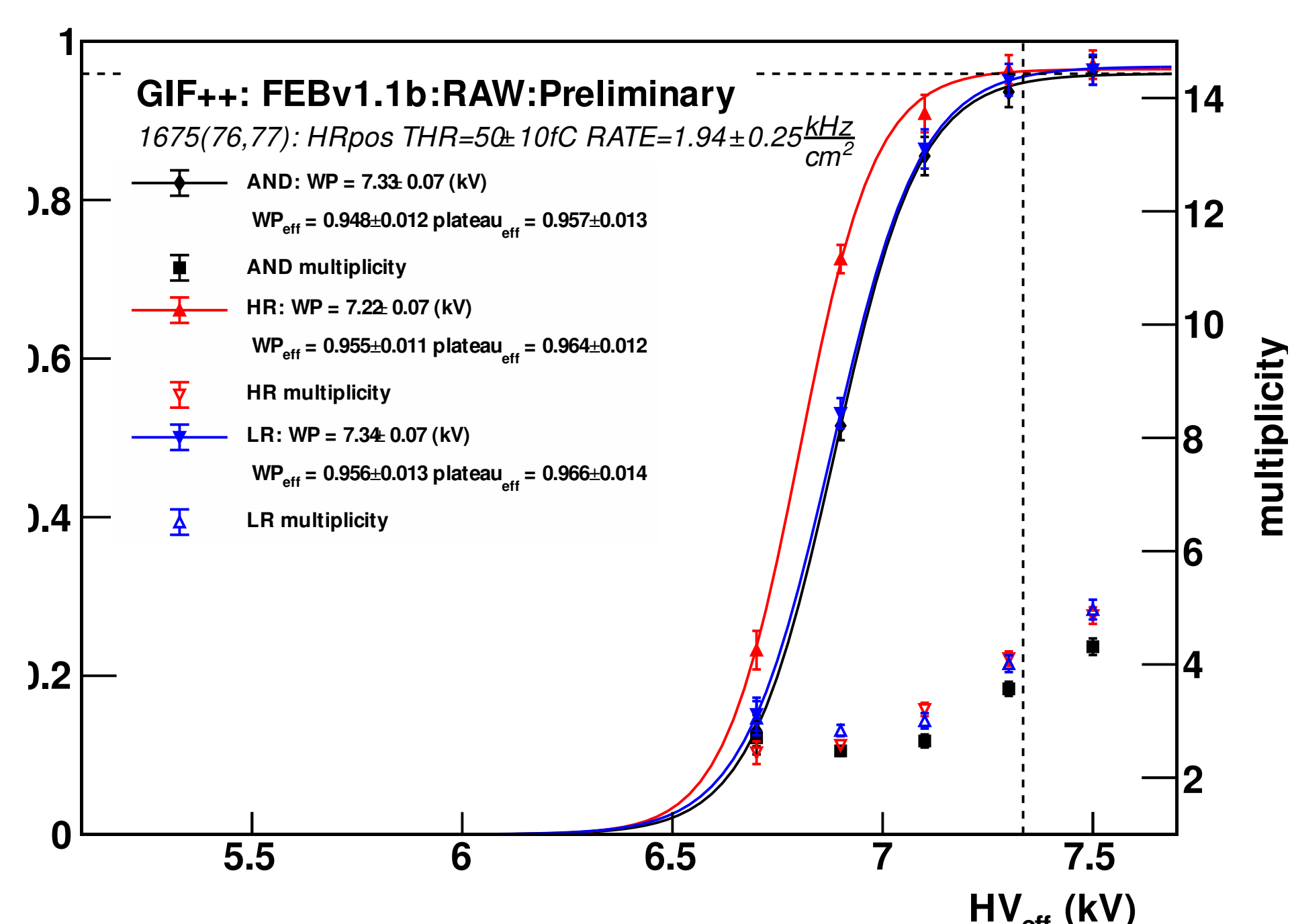
iRPC FEB

The iRPC chambers will demand changes, in comparison with the current system, in terms of design and electronics [1]. In terms of electronics, a completely new FEB is being developed. This one should **(1) ensure the chamber efficiency in a high rate environment (up to 2 kHz/cm^2) and (2) provide information for a 2-dimensional readout**. To achieve the requirements, **the iRPC FEB will use PETIROC ASICs [2]**, with 32-channels each, for pre-amplification and discrimination of strip signals, providing low-jitter trigger with accurate charge and time measurements.

> Each strip end will be connected to one channel of the PETIROC. The digitized signal is sent to a FPGA (Field Programmable Gate Array), where a high resolution Time-to-Digital Converter (TDC) is implemented, allowing 2D measurement of the muon hit by measuring the arrival time difference of the two strip ends.

Figure 2: Muon Efficiency versus High Voltage Effective (HVeff) for the second version of FEB with PETIROC2B (FEBv1b) and the mean value of multiplicity for each side. 'AND' efficiency showing without crosstalk impact. Scintillators placed in the HR of the chamber and covered about 20cm. This setup includes three protected with leads scintillators inside GIF++ (CERN's Gamma Irradiation Facility - September-November 2019 - w/o outside scintillators). FEB thresholds: 50 ± 10 fC.

There are two versions of the iRPC FEB: FEBv0 (only one PETIROC2A and an Altera Cyclone II FPGA) and FEBv1 (with two PETRIOC2B and same FPGA). Figure 3 shows, for FEBv1, the Muon Efficiency versus Effective High Voltage (HVeff, taking into account pressure and temperature effects) and the mean multiplicity, for cosmics data taken at GIF++, considering the High and Low Radius (HR and LR) strip ends and the logical 'AND' of them. Future versions under development includes schematics closer to final version, radiation hard FPGA (PolarFire) and the possibility of a newer version of the PETIROC ASIC (2C, with automatic latching of individual channels).

New Link System

In the CMS experiment, the RPC chambers are readout, controlled and monitored through the Link System, which consists of 1592 electronics boards, divided in two kinds, known as the Link boards (LBs) and Control Boards (CBs), LBs can work as Master LB or Slave LB.

The new link system is being developed around the use of modern components and FPGAs (Field Programmable Gate Array), following a radiation hard design.

> The data transmission rate between the new Link system and RPC back-end electronics increases to 10.24 Gbps and resolution of the Muon hit time improves to 1.5 ns.

Figure 3: Performance of implemented TDC.
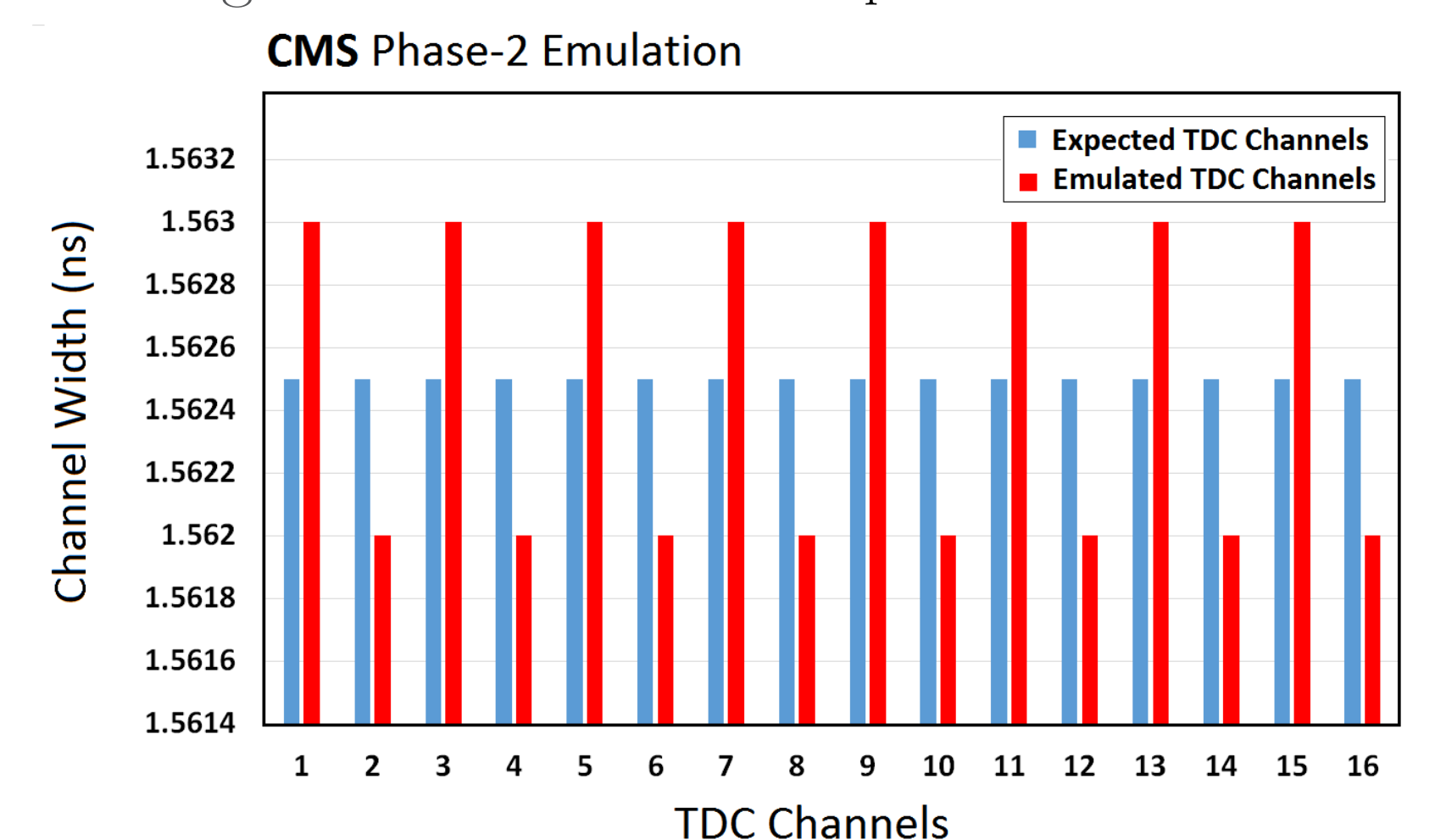
This is achieved by **(1) the use GTX transceivers of the FPGA**, plus preprocessing of data and (2) implementing a high resolution **96-channel TDC in the link board FPGA**. Each TDC channel consists of 16 bins with a time scale of 25/16 ns. Figure 3, shows the emulated channel width, in agrement with the expected 1.56 ns.

Readout and Control Electronics

An extensive Phase-2 upgrade program is also scheduled for CMS Level-1 Trigger [3]. Since RPC is the only Muon detector present in both CMS Barrel and Endcap region, its contribution to CMS Level-1 Trigger upgrade program is important.

The readout and control system (also called back-end) of the RPC (Figure 4) system will be redesigned in order to

Figure 4: RPC readout and control system for Phase-2. Its links will be composed by Slow Control/Monitoring channels (dashed lines) and readout channels (solid lines).

The readout and control system (also called back-end) of the RPC system will be redesigned to:

- include include readout and control of new hardware;
- cope with the requirements of the CMS Level-1 Trigger Phase-2 design;
- sustain maintenability of the system by replacing obsolete hardware.

The new readout, control and monitoring hardware will be installed in the CMS Services Area, away from CMS radiation, and will follow the CMS specification of common hardware platforms for Phase-2, specifically, Serenity boards [4], with ATCA form factor.

> Barrel RPC hits are expected to be distributed to a common CMS Barrel (RPC + DT) hardware, while Endcap and iRPC hits will go to dedicated RPC boards. Those hits will later be distributed to CMS Muon Track Finders and DAQ.
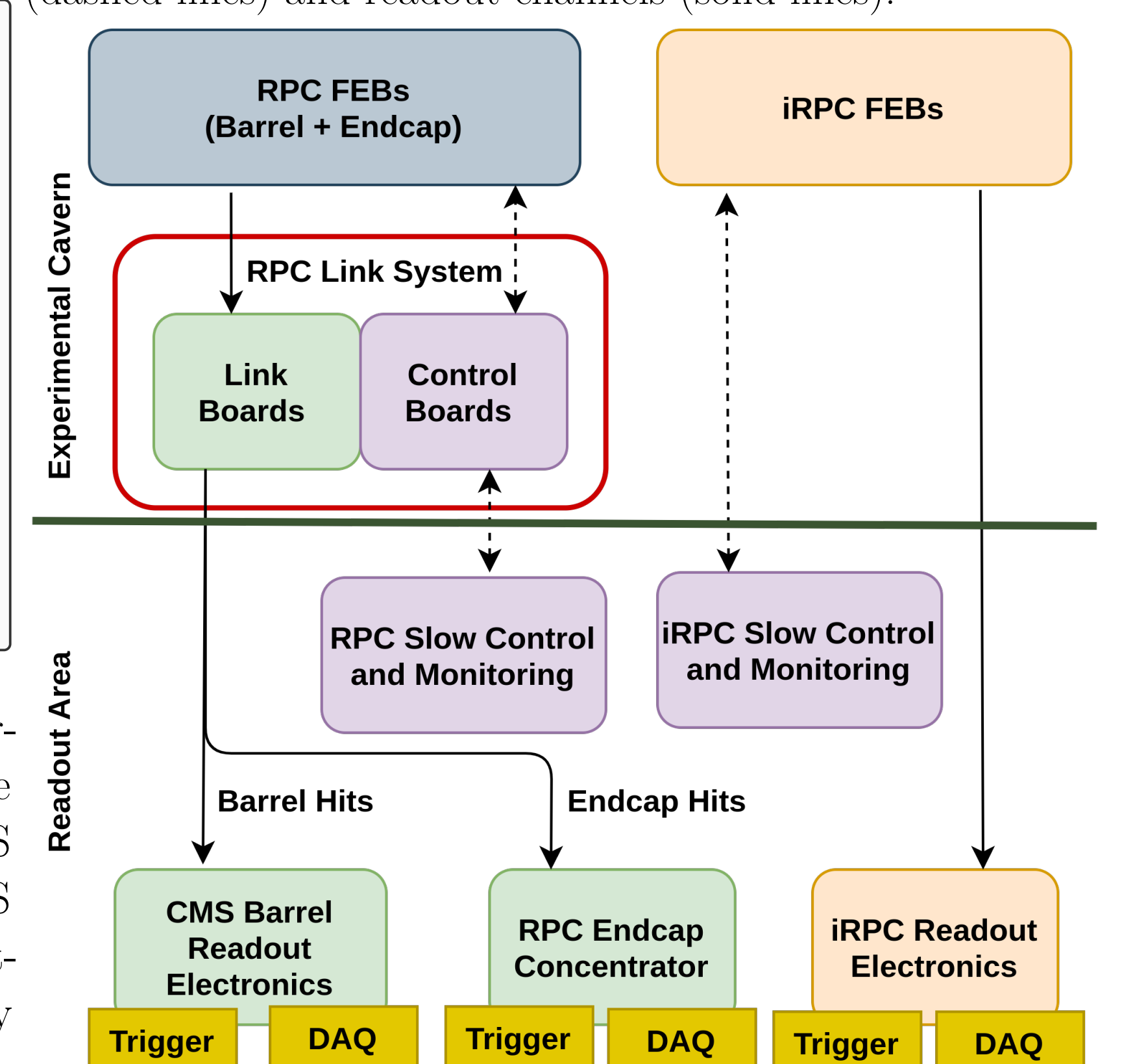
Conclusion

For the next CMS data-taking period (Run3 - starting in 2022), it is awaited that prototypes of the upgrade activities described above will be installed in CMS to take data concurrently with CMS, for validation propose. In preparation for Phase-2 upgrade, a thorough commissioning of prototypes is expected for the next years. Irradiation tests are also planned.

References

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