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Design and qualification of the optical fiber system for the CMS RPC Link System

Andres Leonardo Cabrera Mora for the CMS Collaboration

Abstract

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Design and qualification of the optical fiber system for the CMS RPC Link System

A. Cabrera [i], M. Tytgat [a,1], K. Mota Amarilo [b,2], A. Samalan [b,3], K. Skovpen [b], G.A. Alves [c], E. Alves Coelho [c], F. Marujo da Silva [c], M. Barroso Ferreira Filho [d], E.M. Da Costa [d], D. De Jesus Damiao [d], B.C. Ferreira [d], S. Fonseca De Souza [d], L. Mundim [d], H. Nogima [d], J.P. Pinheiro [d], A. Santoro [d], R. Gomes De Souza [d], M. Thiel [d], A. Aleksandrov [e], R. Hadjiiska [e], P. Iaydjiev [e], M. Shopova [e], G. Sultanov [e], A. Dimitrov [f], L. Litov [f], B. Pavlov [f], P. Petkov [f], A. Petrov [f], E. Shumka [f], P. Cao [g], W. Diao [g], W. Gong [g], Q. Hou [g], H. Kou [g], Z.-A. Liu [g], J. Song [g], N. Wang [g], J. Zhao [g], S.J. Qian [h], C. Avila [i], D.A. Barbosa Trujillo [i], C.A. Florez [i], J.A. Reyes Vega [i], R.Aly [j,l,4], A. Radi [k,5], Y. Assran [l,6], I. Crotty [m], M.A. Mahmoud [m], L. Balleyguier [n], X. Chen [n], C. Combaret [n], G. Galbit [n], M. Gouzevitch [n], G. Grenier [n], I.B. Laktineh [n], A. Luciol [n], L. Mirabito [n], W. Tromeur [n], I. Bagaturia [o], O. Kemularia [o], I. Lomidze [o], Z. Tsamalaidze [o,7], V. Amoozegar [p], B. Boghrati [p], M. Ebrahimi [p], F. Esfandi [p], Y.Hosseini [p], M. Mohammadi Najafabadi [p], E. Zareian [p], M. Abbrescia [q,r], N. De Filippis [q,s], G. Iaselli [q,s], F. Loddo [q], G. Pugliese [q,s], D. Ramos [q], L. Benussi [t], S. Bianco [t], S. Meola [t,8], D. Piccolo [t], S. Buontempo [u], F. Carnevali [u,v], L. Lista [u,v,9], P. Paolucci [u,10], F. Fienga [w], A. Braghieri [x], P. Montagna [x,y], C. Riccardi [x,y], P. Salvini [x], P. Vitulo [x,y], T.J. Kim [z], E. Asilar [z], Y. Ryou [z], S. Choi [aa], B. Hong [aa], K.S. Lee [aa], J. Goh [ab], J. Shin [ab], Y. Lee [ac], I. Pedraza [ad], C. Uribe Estrada [ad], H. Castilla-Valdez [ae], R. Lopez-Fernandez [ae], A. Sánchez Hernández [ae], M. Ramírez García [af], D.L. Ramirez Guadarrama [af], M.A. Shah [af], E. Vazquez [af], N. Zaganidis [af], A. Ahmad [ag], M.I. Asghar [ag], H.R. Hoorani [ag], S. Muhammad [ag], J. Eysermans [ah],
on behalf of the CMS Collaboration

[a] *Vrije Universiteit Brussel, Brussel, Belgium*
[b] *Universiteit Gent, Gent, Belgium*
[c] *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[d] *Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[e] *Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[f] *Faculty of Physics, University of Sofia, Sofia, Bulgaria*
[g] *Institute of High Energy Physics and University of the Chinese Academy of Sciences, Beijing, China*
[h] *School of Physics, Peking University, Beijing, China*
[i] *Universidad de Los Andes, Bogota, Colombia*
[j] *Physics Department, Faculty of science, Helwan University, Cairo, Egypt*
[k] *Department of Physics, Faculty of Science, Ain Shams University, Cairo, Egypt*
[l] *The British University in Egypt, Cairo, Egypt*
[m] *Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
[n] *Institut de Physique des 2 Infinis de Lyon, Villeurbanne, France*
[o] *Georgian Technical University, Tbilisi, Georgia*
[p] *Institute for Research in Fundamental Sciences, Tehran, Iran*
[q] *INFN Sezione di Bari, Bari, Italy*
[r] *Università di Bari, Bari, Italy*
[s] *Politecnico di Bari, Bari, Italy*
[t] *INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[u] *INFN Sezione di Napoli, Napoli, Italy*
[v] *Università di Napoli 'Federico II', Napoli, Italy*
[w] *Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione - Università Degli Studi di Napoli Federico II, Napoli, Italy*
[x] *INFN Sezione di Pavia, Pavia, Italy*
[y] *Università di Pavia, Pavia, Italy*
[z] *Hanyang University, Seoul, Korea*
[aa] *Korea University, Seoul, Korea*
[ab] *Kyung Hee University, Department of Physics, Seoul, Korea*
[ac] *Sungkyunkwan University, Suwon, Korea*

Email address: `andres.leonardo.cabrera.mora@cern.ch` (A. Cabrera)

[1] Also at Ghent University, Ghent, Belgium
[2] Now at UERJ, Rio de Janeiro, Brazil
[3] Now at PSI, Villigen, Switzerland
[4] Also at Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
[5] Also at Sultan Qaboos University, Muscat, Oman
[6] Also at Suez University, Suez, Egypt
[7] Also at an institute or an international laboratory covered by a cooperation agreement with CERN
[8] Also at Università degli Studi Guglielmo Marconi, Roma, Italy
[9] Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy
[10] Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

[ad]Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
[ae]Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
[af]Universidad Iberoamericana, Mexico City, Mexico
[ag]National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
[ah]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Abstract

A new off-chamber electronics system, called the Link System, for the CMS RPC chambers will be installed during LHC Long Shutdown 3. The new Link System will improve the time resolution to 1.56 ns compared to the current value of 25 ns. The Link System requires a new infrastructure of low attenuation loss, fiber optic cables to achieve a high-speed data transmission rate of 10 Gbps. The Link System includes one redundant channel for data transmission on the Master Link Boards and two redundant channels for data transmission and reception on the Control Boards. The optical fiber system has been optimized to determine the number of cables, the number and location of patch panels, and the power budget required to support different connectors, transmission distances, and fiber types.

Keywords: Optical fiber, RPC Link System, OTDR, CMS

1. RPC upgrades during the LHC Long Shutdown 3

During the LHC Long Shutdown 3 (LS3), between 2026 and 2029 (see Figure 1), the RPC system will be upgraded in two ways. One of them is the installation of improved RPC (iRPC) chambers at stations RE3/1 and RE4/1 in the endcaps, as shown in Figure 2. This will extend the $|\eta|$ range of the RPCs to 2.4. The other upgrade is the replacement of the existing RPC Link System with new, high-performance electronics. This involves the replacement of electronics boards in crates, called Link Board Boxes, located outside the chambers. Each Link Board Box contains two different types of electronics boards: Control Boards, for slow control, and Master Link Boards, that transmit the detector signals.

The new Link System will improve the time resolution of the RPCs to 1.56 ns from the current value of 25 ns. The data transmission rate will be increased to 10.24 Gbps from 1.6 Gbps for the Master Link Boards and the rate for the Control Boards will be increased to 4.8 Gbps [1]. The connection between the Front-End Boards (FEB) installed in each chamber and the new Link System will be made with the existing LVDS copper cables (see Figure 3).

The boards of the new Link System include redundant channels. Each Master Link Board includes a redundant transmit channel (called Tx_2 in Figure 4), and each Control Board includes two redundant channels, one for transmit and one for receive (Tx_2 and Rx_2 respectively in Figure 4). This redundancy not only allows flexibility in case the signal needs to be duplicated but also adds an additional component of robustness to the system by allowing easy replacement of any defective channel.

2. Fiber optic requirements for the new Link System

As seen in Table 1, 1440 fiber optic cables are required for the barrel and 1152 for the endcaps. These numbers include cables dedicated to the redundant channels for the Control Boards

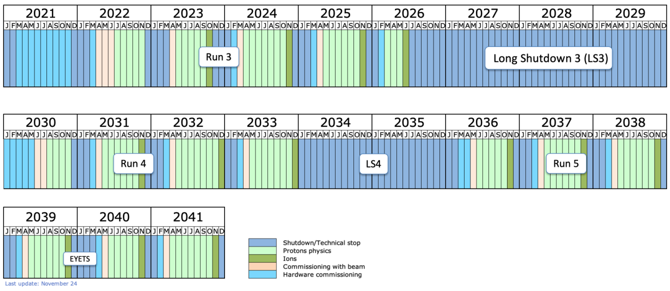

Figure 1: Longer term LHC schedule version updated on November 2024 [2].

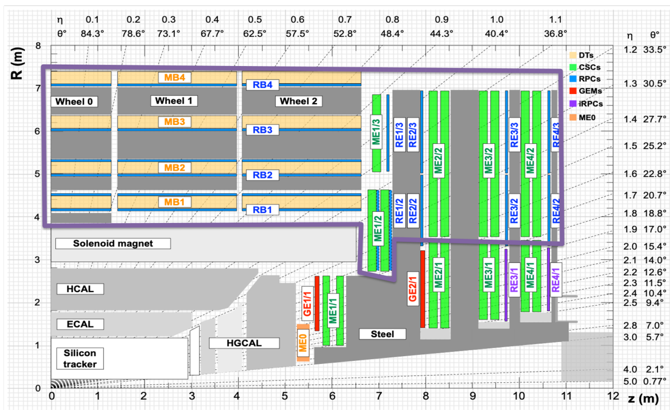

Figure 2: An R-z cross section of a quadrant of the CMS detector, including the Phase-2 Upgrade (RE3/1, RE4/1, GE1/1, GE2/1, ME0). The acronym iRPCs in the legend refers to the new improved RPC chambers RE3/1 and RE4/1 [3]. The area enclosed by the purple boundary contains the current RPC system which will be impacted by the new Link System upgrade.

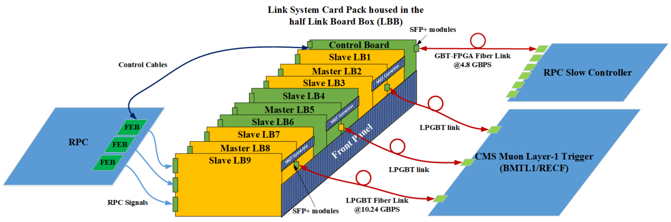

Figure 3: Schematic illustrating the connection between the chamber Front-End Boards (FEB) and the new Link System. This connection is made by copper LVDS cables, represented by dark blue and light blue arrows. The data transfer rate for the Control Board (CB) is 4.8 Gbps and 10.24 Gbps for the Master Link Boards (MLBs). These boards will replace equivalent boards in the existing Link System.

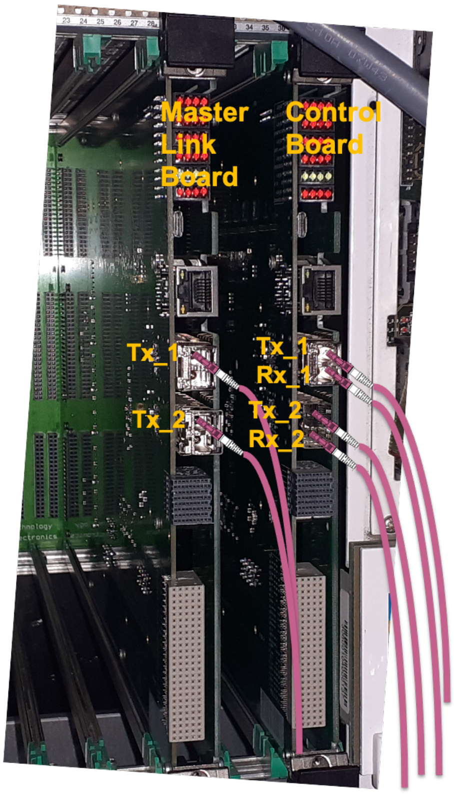

Figure 4: Side view photo of a Control Board and Master Link Board inside a Link Board Box. The Master Link Board design includes a redundant transmission channel (Tx_2). The Control Board design includes two redundant channels, one for transmission (Tx_2) and one for reception (Rx_2).

and Master Link Boards. The final destination of the cables connected to the Control Boards in the experimental cavern is the RPC Backend in the service cavern. On the other hand, the cables connected to the Master Link Boards will be connected to the Barrel Muon Track Finder Layer 1 (BMTF L1) for the chambers in the barrel and to the RPC Endcap Cluster Finder (RECF) for the chambers in the endcap, both located in the service cavern (see Figure 5).

To satisfy CERN safety requirements for underground facilities, fiber optic cable is required to have a Low Smoke Zero Halogen (LSZH) cladding. Such cladding emits little smoke and no halogens when exposed to high heat sources. Since fibers in the experimental cavern are exposed to radiation, the fiber core must be phosphorus free.

To minimize optical attenuation and dispersion in the fiber cables and connectors at the patch panels (see Figure 5), it is important to use a high quality fiber: Optical Multimode 4 type (OM4). This fiber type has a core diameter of 50 μm and a cladding diameter of 125 μm. OM4 core fiber has a lower modal dispersion and longer attenuation length than OM3 fiber, supporting a larger data rate for the same cable length. Each optical connector results in an insertion loss, with typical values between 0.25 and 0.5 dB depending on connector quality. Typical transmission values with OM4 fiber for distances less than 150 meters are between 40 and 100 Gbps, more than satisfying the required transmission rate of 10.24 Gbps for Master Link Boards and 4.8 Gbps for Control Boards.

	Barrel			
	Used	**For redundancy**	**Spares**	**Total**
Fibers per sector	9	9	6	**24**
Fibers per trigger tower	54	54	36	**144**
Total fibers	540	540	360	**1440**
	Endcap			
	Used	**For redundancy**	**Spares**	**Total**
Fibers per sector	8	8	8	**24**
Fibers per trigger tower	48	48	48	**144**
Total fibers	384	384	384	**1152**

Table 1: Number of fiber optic cables for the new link system for the barrel and endcap.

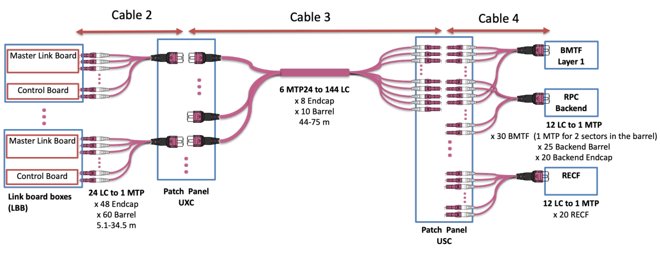

Figure 5: Schematic drawing showing the required fiber connections for the new Link System. UXC stands for Underground eXperimental Cavern and USC stands for Underground Service Cavern. To reach their final destination, the fiber optic cables from the Link Boards must pass through two patch panels, one located in the experimental cavern (UXC) and the other located in the service cavern (USC). The final destination of fibers from the Control Boards is the RPC backend in the USC. Fibers from the Master Link Boards of barrel chambers have final destination at the Barrel Muon Track Finder Layer 1 (BMTF L1) in the USC, while those from the endcaps have final destination at the RPC Endcap Cluster Finder in the USC (RECF).

3. Irradiation test on the fibers

Using the CERN High energy AcceleRator Mixed field facility (CHARM), the performance of a fiber optic cable was measured after an integrated radiation dose equivalent to 10 years of operation of the High Luminosity LHC (HL-LHC), Figure 6 shows the mounting grid holding the fiber cables. Cables from different manufacturers had different colors. Each cable was analyzed with an Optical Time Domain Reflectometer (OTDR) before and after irradiation. The OTDR sends a short light pulse to the fiber under test through an optical coupler. The back reflected light is analyzed at a detector to measure the distributed attenuation along the fiber, to check the homogeneity of the fiber, to discover and identify damage, which may have occurred during the mounting of the fiber, and to observe losses and back reflections from connectors or optical components [4]. The data show no significant change in attenuation (see Figure 7) after an accumulated radiation dose of 147 Gy, nearly 15 times the accumulated dose of 10-12 Gy expected after ten years of HL-LHC operation.

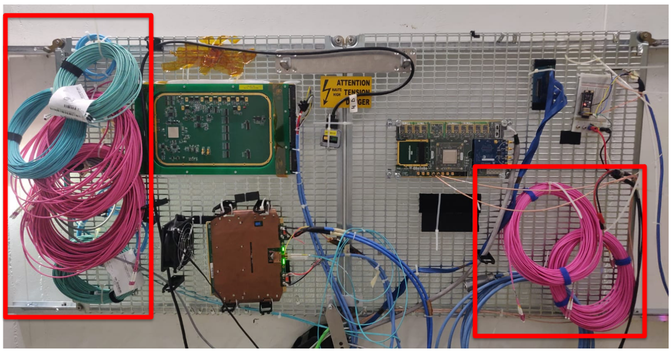

Figure 6: Photograph of a mounting grid in the CERN High energy AcceleRator Mixed field facility (CHARM) holding components for irradiation. The red boundary lines indicate the regions where the fiber optic cables are located. They received a cumulative dose of 147 Gy.

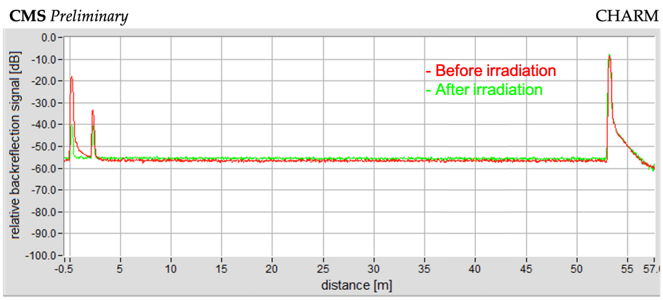

Figure 7: Data obtained with the Optical Time Domain Reflectometer (OTDR) before and after irradiation of the optical fiber. There is no significant change in attenuation after an accumulated radiation dose of 147 Gy [5].

4. Summary

The installation and testing of the optical fibers will be a crucial step in commissioning the new Link System that will be installed during LHC LS3. The design and routing for the optical fiber connection between the new Link System and the RPC backend/BMTF/RECF is ready. The CHARM test shows that there is no significant change in attenuation due to radiation. The next step, fiber acquisition, is in process.

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