Questions: 6th November 2017

Answers: 18th November 2017

CMS MUON TDR Review (RPC part)

Please find below a set of additional questions/comments. In some cases *(marked in bold)* we explicitly ask for additions to the TDR. As usual, no attempt was made to sort the questions according to importance. At the end of the questions we included also some additional comment and recommendations.

Q43. (Follow-up of Q1)
One of the main motivations of the various upgrades of electronics systems is making them with the phase 2 trigger rate and event pileup. The strategy for testing this goal for DT, CSC and RPC has been illustrated. The equivalent strategy for GEMs is missing.

The test strategy of the electronics is a point to be added in the TDR.

RPC: add a small section to TDR

This is what we wrote for Q1
The test of the new Link System will be done by injecting simulated data with volumes and rates as those expected at HL-LHC (with sufficient safety margin) and provide simulated trigger signals at the expected rate. The tests will be repeated also on a test bench at the 904 laboratory where the full chain detector and electronics will be installed. The test of front end electronics for RE3/4-1 chamber will be performed by using special firmware that satisfies the new latency requirements and by generating trigger signal at the expected HL-LHC rates.

In RPC readout system, the trigger rates and bandwidth limitations come from the link bandwidth and the radiation tolerant firmwares of the Link board systems. In order to test of the new Link System with a similar condition of HL-LHC at the expected trigger rates (with sufficient safety margin), the same simulated signals with volumes and rates will be injected into the input channels of the Link board system. The tests will be repeated also on a test bench at the 904 laboratory where the full chain detector and electronics will be installed.

TO be rephrased

Q44. (Follow-up of Q8)
The internal organization of the project for the CMS muon system upgrade has been described in detail in the answer to this question.

We consider this information should be added to the TDR.

Anna will update the text in Chapter 9 according to the answer we give in Q8. Once done, we will state here that the TDR is updated per the request

Q45. iRPCs:
Detailed information and about the QA/QC procedures is needed.

This point should also be improved in the TDR.

RPC: **(1)** add a brief answer here and
(2) update TDR to include a section on iRPC QA/QC (state here it is done, once done)

The QA/QC in iRPC will follow a similar protocol to the one applied in RE4 production in 2010. Quality Control (QC) will be applied at four levels: Chamber components, HPL gaps, Chamber assembly and cosmic test validation in construction site, Chamber long-term performance validation at CERN before installation. For each of them a precise acceptance protocol will be defined and applied in the involved sites during mass production. All collected data will be recorded in a Construction DB, always accessible online by all RPC collaboration members.

QC1 level will be applied to basic chamber components: on-detector electronics, HPL batch production with control on resistivity level, selection of gas pipes, unions, HV/LV/signal connectors/cables, cooling pipes/elements. For HPL it will be done a visual inspection and it will be controlled the level and uniformity of resistivity in the production site. For all the other components there will be a visual inspection and the production batch will be recorded in construction DB.

QC2 will be applied to chamber elements: HPL gaps, cooling circuit. For HPL gaps several parameters will be recorded during and after the mass production: visual inspection, gas tightness and spacer gluing, resistivity and dark current. For cooling circuits a pressure test will be performed with defined max leak rete as pre-agreed with CMS Cooling team.

QC3 will be applied to full chamber soon after production in two steps. QC3.1 (Chamber assembly tests) will be performed: visual inspection, cooling circuit test, connectivity tests, electrical test (LV, threshold). QC3.2 (Chamber cosmic tests) will be performed: dark current (in first 24h, at different HV, ohmic current), cosmic ray test measurements (efficiency, mean cluster size, noise rate, dark current in operation).

Once the chamber is received at CERN, the QC4 final validation test will be performed to secure that no damage was due to transport and to validate the chamber long term performance. Again two levels of QC will be applied. QC4.1 (Final Chamber tests), meaning: Connectivity, electrical, leak (gas/cooling) and dark current tests. QC4.2 (Long-term stability tests), meaning: dark current monitored for 2 weeks at operating voltage.

Q46. iRPC Quality Control

The roadmap towards the final prototype and production of the detectors should be detailed a bit further. More precise information on the expected Quality Controls would be beneficial as the new chamber are different in many ways from the legacy RPCs. The committee notes that aspects like gas leaks etc. rely on the good experience in the production of the earlier Endcap chambers with no extra detail.

As stated in previous answer the QA/QC in iRPC will follow a similar protocol to the one applied in RE4 production in 2010.

4 level of QC will be applied: chamber components, HPL gaps, Chamber validation in construction site, long term chamber validation at CERN before installation. For each of them a precise acceptance protocol will be defined and applied in the involved sites during mass production. All collected data will be recorded in a Construction DB, always accessible online by all RPC collaboration members.

Concerning possible differences with previous RPC production for Endcap and Barrel, the iRPC are very similar to the CMS previous RPC endcap chamber, a part of the new HPL panel thickness (1.4mm instead of previous 2.0 mm) and the type of strips and electronics.

HPL different panel thickness will demand additional care in HPL gap manufacturing QC1, and gap manufacturing QC2. The strips and electronics will follow specific QC1 as done for previous chamber productions.

No change will be applied in term of gas piping inside the chamber wrt previous CMS endcap RPC chambers, so similar performance in term of negligible gas leaks are expected, following a similar gas leak QC protocol.

The RPC suffering severe leaks in CMS are those in the barrel. These chambers have significant larger dimension wrt endcap ones. This was forcing to split gap for the same layer in 2 elements and consequently additional link gas pipe elements were needed (T and I shape). Unfortunately, it turn out that these components were quite fragile in long term stability and today they cause the major element of leak in the CMS RPC barrel chambers. Being inside the chamber these elements are accessible only with chamber extracted from CMS yoke structure. This reduced accessibility is significantly slowing down their curing possibilities.

These components are NOT needed/present in the CMS RPC endcap chambers and will NOT be used in iRPC chambers.

RPC: answer the question (note a partial overlap with Q45)

RPC: answer the question (illustrate the list with pictures)

Q47. iRPC gas-tightness. It would be desirable to see an explicit list of components (e.g. in the gas supply manifold) which are the main source of leaks in the existing RPCs, and an explanation for how these components are being avoided/substituted in the iRPCs. In addition, will there be a more extensive leak-checking campaign before & during installation?

Answer:

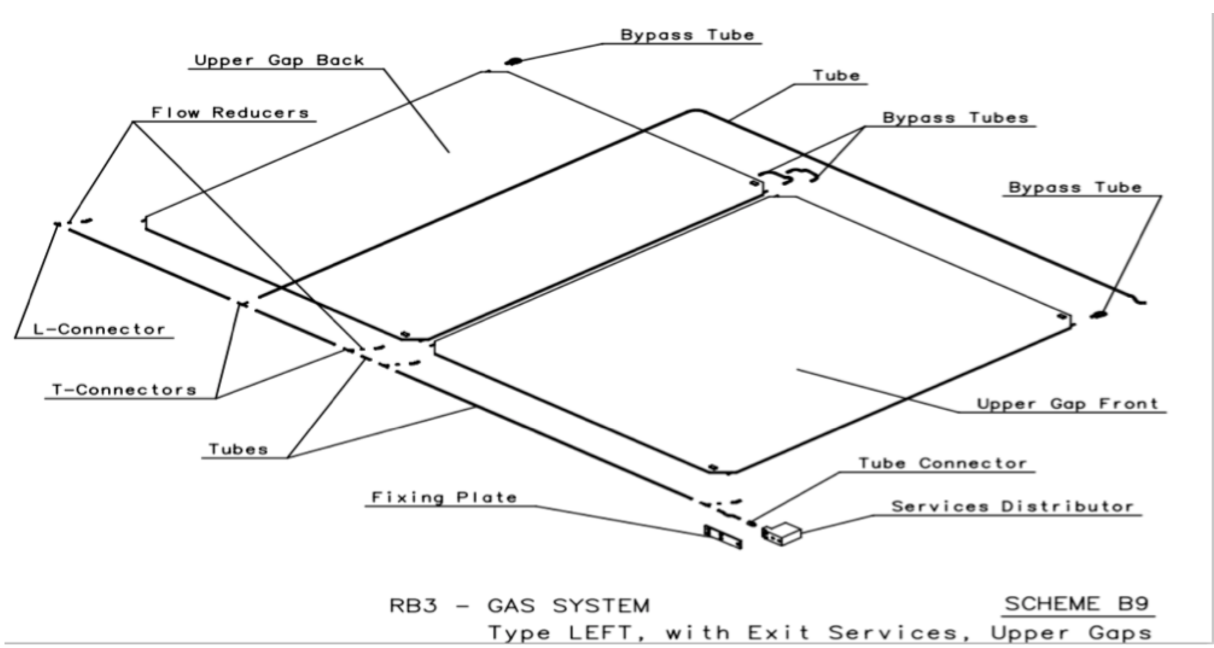
As already stated in previous 2 questions, for what concerning the gas leak tests, as done for CMS endcap RE4 chamber production, we will start the QC at level of QC1 securing the selection of the right material for gas pipes, inlets and unions for patch panel. In QC2 we will check the tightness at level of gap production applying validation criteria defined in term of max leak rate acceptance $5x10^{-7}$ mbar l/s. The QC will follow after the chamber construction in the assembly sites, applying the same acceptance test during the QC3 and during long term validation test at CERN during QC4. All these controls will secure that no leak has been created during the HPL gap/chamber transport and manipulation in different labs.

With this QC protocol during the RE4 production we have secured ALL the constructed chambers to suffer NO leak during QC4 and in CMS, successfully running now for 4 years.

Similar stable performance were obtained in the older CMS RPC endcap chambers, running since 10 years now.

As explained in the answer to Q46, the gas leak in CMS RPC is happening in the RPC Barrel chambers. They were demanding additional components (not used in the endcap chambers) in order to join 2 adjacent gaps in the same chamber layer (see Upper Gap Back and Front in fig1). This action was demanded because of the significantly larger dimension of barrel chambers wrt endcap ones.

Here in the following some technical drawings of the CMS RPC barrel and endcap chambers, showing the major differences in the gas distribution inside the barrel chamber mechanical structure. The weak element is the so called T-Connector, visible in the Barrel chambers and completely absent in the endcap chambers.



TDR sentence (only the first sentence in the answer): to BE completed

The QA/QC in iRPC will follow a similar protocol to the one applied in RE4 production in 2010.
Quality Control (QC) will be applied at four levels: Chamber components, HPL gaps, Chamber assembly and cosmic test validation in construction site, Chamber long-term performance validation at CERN before installation. For each of them a precise acceptance protocol will be defined and applied in the involved sites during mass production. All collected data will be recorded in a Construction DB, always accessible online by all RPC collaboration members.

Q48. On the iRP C electronics:
The roadmap and the integration into a final prototype has not been yet established or fully demonstrated. From the TDR and presentation the topic appears even more in an R&D phase with the final CMOS chip still to come. Some details about the expected CMOS prototypes, their differences w.r.t. to the actual Petiroc system, the production schedule, possibly supported by measurements if available would be useful. Furthermore, a few statements on fallback options and on the trigger performance for the case the 2D readout scheme would not perform as expected would be also appreciated.

What would the advantages if lower threshold in the Front end could be used.
Lowering HV? gas with lower gas gain? Longevity of chambers?
Which is the **technology behind the PETIROC Si-Ge chip?**
Is it BiCMOS? What is the motivation to switch to CMOS?

A PCB of the same size as the one proposed in the TDR has been produced. It has all the required qualities. A FE board hosting one PETIROC and one TDC to deal with 32 channels of the PETIROC was also produced and successfully tested on the PCB. The FE and PCB are currently being tested on one RE3.1-iRPC prototype.
ADD a picture of the chamber (PCB and PETIROC) ..Gabriella
ADD a plot with signal injected from one side showing no reflection .. gabriella

The next step consists in producing one FE board hosting 6 PETIROCs needed to readout 96 strips per chamber. There is no technical challenge moving from a board with one ASIC to a board with a few ASICs. The design of the new board is already conceived and the production should take place within 5 months. The plan is to equipped a real size of iRPC and test it at Test beam/GIF++ in May/Jun 2018.
The new version of the chip based on CMOS technology will increase the safety margin in two fields:

1- Lower threshold. The lowest threshold that can applied with the current PETIROC is about 55 fC. The new version intends to reduce the threshold from 55fC down to 10fC. This will allow us to work at lower HV and thus to reduce the average avalanche charge while keeping the same efficiency. The accumulated charge is one of the important parameters to slow down the aging of the detectors.

2- radiation hardness: replacing the SiGe 350 (BiCMOS) by TSMC 130 (CMOS) increases the tolerance to radiation. Even though the present PETIROC technology is expected to perform well up to 10^13 neutron fluence, which is the expected one in the area where the ASICs will be placed, the new chip will allow to withstand rates higher than 10^14 neutron. The Bipolar transistor of the SiGe BiCMOS are more sensitive to radiation and therefore going to CMOS polar transistor reduces the sensitivity to radiation. In addition the passage from 350 nm to 130 nm is also a way to reduce this sensitivity to radiation **[ref].**

As a fallback solution, the use of a low noise electronics [Si techonology] and HARDROC2 ASIC (SiGe 350 nm) has been already demonstrated to work at low threshold capability on small iRPC **[REF1 - REF2].** In this case the development of the FEB design will be need and it will take 1 year.
This solution should not delay the starting of the RPC chamber production which is scheduled to be in Jan 2020. The HARDROC2 ASIC (SiGe 350 nm) has a 64 channels and a lower threshold of 10 fC, but time resolution few hundreds ps, leading to a worse determination of the Y position.

To be added that the 2d readout has benefit on cost and mach costuction and this will improved eff.. And resolution in y for backgroudn reduc……..

Are these two motivations strong enough to justify the new CHIP??
What about the roadmap for test the new chip??
This technology is the one used in the HGCAL and we can take profit of their developing….. Add the road road map…

Q49. - iRPC design criteria and electronics:
The advantages of the new read-out scheme with signal collection from both strip ends need to be further illustrated. Dedicated simulation showing that this read-out approach can properly work at high luminosity is desired.

In summary, additional information about iRPC novel R-O should be added to the TDR.

RPC: **(1)** answer the question briefly here
(2) update TDR with a fuller answer (and state it is done, once done)

NB (Andrey): For the first part of the question, we should bring up again (a) cost savings and (b) quantify at least on a back-of-envelope basis how often the combinatorial background in CSCs can be resolved with iRPCs. For the second part of the question, there was an explicit question at the Oct 31 meeting asking to assess the probability of a random hit hitting a strip with a muon signal and, thus, spoiling the muon hit time and y-coordinate.

In order to match the CSC segmentation in this eta region, the iRPC should have been segmented in five partitions with increased number of electronics channels and additional complications in terms of chamber construction to allow the cabling of all the strips. Moreover with five partitions we should not have space to put additional front end boards on the high eta region. The new readout schema allows us to keep the correct spatial resolution with less channels and easier readout layout and with the possibility to put the front end boards in a position where the background is not too high.

The probability of a double hit on the same strip spoiling the muon time and y-coordinate has been estimated as about 0.6%. We assumed the following:

- Average rate in the RE31 and RE41 about 500 Hz/cm2
- Safety factor of 3
- Cluster size of 2 and surface of one strip 158.4 cm x 0.87 cm

We expect to have per second 381177 hits and the average time interval between two hits is then 2625 ns. The duration of the signal is about 10 ns (this is also the maximum time for the signal to travel across the strip). The electronics introduces almost no additional dead time (< 1 ns). The TDC clock is 2.5 ns and a dead time of 2 periods is applied (5 ns).
Therefore if two signals arrive in less than 16 ns there will be confusion and theY will not determined adequately. This represent approximately 16/2625 = 0.6%. If take additional safety margin of 5 ns for the electronics the dead time will be 21/2625 = 0.8%.

Q52. Test of radiation hardness for the electronics.
A breakdown and a justification of the safety factors applied for radiation test are requested. In particular, it would be interesting to understand potential differences, if any, to the approach taken by other LHC experiments.

Manuel will prepare the answer (safety factor is always 3, find out safety factors used by ATLAS/LHCb, check if we can find in literature how broad the distributions of doses-to-fail are, etc.)

Q54. Do you consider 2-dimensional readout of RPC using TDC?

Yes, the 2-dimensional readout is done using the TDC which is mounted directly on the front-end boards of the chambers. The Y coordinate measurement is done and immediately sent to the trigger system.

Is it used for L1 trigger? What would be the impact for trigger performance?

As in phase-1 the RPC information will be available at L1 trigger. The phase-2 BDT will be retrained and tuned to properly use the local Y information as well as the time measurements.

In phase-1 the local Y information is used in all trigger modes (or stations participating in the trigger decision) to provide the correct **Θ** coordinate of the muon candidate.

The contribution from station 3 and 4 to the pT regression is the most important due to the fact that it has the longer lever arm (see arrows in the list of features participating in the BDT) in the table below [1].

Four-Station Modes													
Mode	**Feature**	$\Delta\phi_{12}$	$\Delta\phi_{23}$	$\Delta\phi_{34}$	sign	$\Delta\theta_{14}$	B_1	B_2	B_3	B_4	FR_1	θ	Mode
1-2-3-4	**Bits**	7	5	4	2	2	2	1	1	1	1	3	1

Three-Station Modes												
Mode	**Feature**	$\Delta\phi_{12}$	$\Delta\phi_{23}$	sign	$\Delta\theta_{13}$	B_1	B_2	B_3	FR_1	FR_2	θ	Mode
1-2-3	**Bits**	7	5	1	3	2	1	1	1	1	5	3
Mode	**Feature**	$\Delta\phi_{12}$	$\Delta\phi_{24}$	sign	$\Delta\theta_{14}$	B_1	B_2	B_4	FR_1	FR_2	θ	Mode
1-2-4	**Bits**	7	5	1	3	2	1	1	1	1	5	3
Mode	**Feature**	$\Delta\phi_{13}$	$\Delta\phi_{34}$	sign	$\Delta\theta_{14}$	B_1	B_3	B_4	FR_1	FR_3	θ	Mode
1-3-4	**Bits**	7	5	1	3	2	1	1	1	1	5	3
Mode	**Feature**	$\Delta\phi_{23}$	$\Delta\phi_{34}$	sign	$\Delta\theta_{24}$	B_2	B_3	B_4	FR_2	–	θ	Mode
2-3-4	**Bits**	7	5	1	3	2	1	1	1	–	5	4

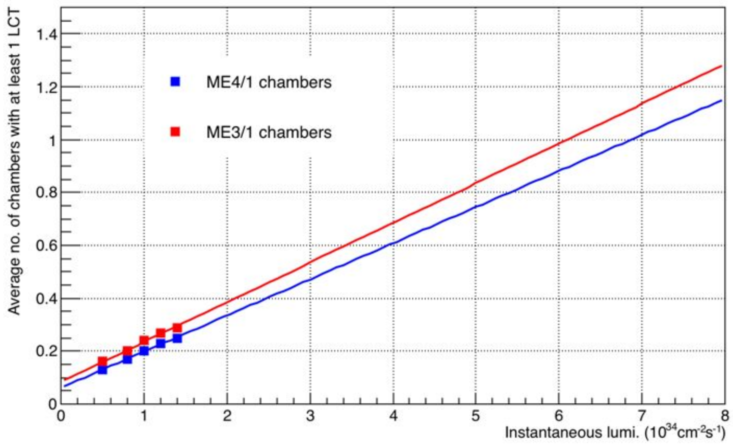
Two-Station Modes									
Mode	**Feature**	$\Delta\phi_{XY}$	$\Delta\theta_{XY}$	B_X	B_Y	FR_X	FR_Y	θ	Mode
X-Y	**Bits**	7	3	3	3	1	1	5	7

Table 1: The compression scheme of the variables used for the BDT-based momentum assignment for each mode. The variables are compressed into a 30-bit word. $\Delta\phi_{ij}$ ($\Delta\theta_{ij}$) denotes the bending angle in ϕ (θ) between stations i & j; "sign" encodes the signs of the later $\Delta\phi_{ij}$'s relative to the first $\Delta\phi_{ij}$ for the mode. the "B" variables indicate whether the hits come from CSC or RPC; the "FR" variables indicate whether the CSC hit is in the front- or rear-positioned chamber; and θ is the estimate of the track polar angle. There are 6 two-station modes: 1-2, 1-3, 1-4, 2-3, 2-4 and 3-4 that use the same scheme.

The CSC local Y / ϴ measurement is not possible if two muons cross the same CSC chamber at the same time.

Using a data-driven method (minimum bias 2016) we estimate that at L=5x10^{34}cm^{-2}s^{-1} the chance to find an LCT in any given ME3/1 chamber will be about 0.8/36 =2.2% (ME4/1 chambers are similar). When EMTF tries to find a L1 muon, it checks and uses LCTs from 3 consecutive BXs. So overall, if there is a muon going through MEx/1 chambers, the chance to have an extra track in ME3/1 or ME4/1 chamber with the muon is about (0.8/36)x3x2=13% [2].

TO be estimated the impact on solving the ambiguity using 2 D readout (with 2 cm resolution along y and with 10 cm resolution).



[1]http://cms.cern.ch/iCMS/jsp/openfile.jsp?type=CR&year=2017&files=CR2017_361.pdf
[2] Study done CSC DPG by J. Wang

Physics:
(1) answer the question (AK: can be easily done; e.g., we have a similar plot for the tau3mu analysis).
(2) Add the plot to TDR and state it is, once done

*Given the fact that the physics case is the main motivation for the muon extension, **we recommend CMS to revisit the TDR chapter on physics motivation,** in order to reinforce the physics case and to improve the justification for the particular detector upgrade proposed.*

PHYSICS: *added the AFB analysis to TDR chapter as well.*

ANNA: LET'S PREPARE SOMETHING LIKE THIS "OLD" TABLE...OR SIMILAR

Channel	Motivation	Detector	Observable
$H \to Z^*Z \to 4\mu$	Sensitivity increase thanks to acceptance and pile-up rejection with timing	ME0	Efficiency, muon fake rate, pt resolution,vertexing
$Z' \to \mu\mu$ (A_{FB} if Z' will be discovered before 2023)	High pt muon performance, alignment studies	All	Pt Resolution Charge assignment,Alignment
Displaced muons from Dark SUSY particles	L1 Standalone Muon trigger, Offline Standalone Muon reconstruction	All	Trigger efficiency and rate vs decay lenght Sig/Bkg discriminating variables (Lxy, dxy, n hits,track chi2, tof) Selection efficiency vs cut

HSCP	TOF measurement	RPC/DT	Sig/Bkg discriminating variables: tof,pT Trigger efficiency and rate vs pT
τ –•μμμ	L1 trigger Pile-up rejection with vertexing (thanks to timing) Increase of acceptance	ME0	Sig/Bkg discriminating variables (#hits,angles,DR,vertex variables) Selection efficiency vs cut Trigger rate and efficiency vs p, eta

Physics:
(1) answer the question
(2) update TDR as needed and state it is done, once done

NB (Andrey): I think we can satisfy the question if (a) we add the A_{FB} results and (b) give a brief summary of improved sensitivities due to the muon system upgrades for all (or almost all) analyses we put forth as illustrations in TDR.

R5. *For all subprojects, a comprehensive oral explanation of the schedules and milestones for the production and the steps towards it would be important and to point out explicitly the critical path items and risks in the schedule. We understand this is under review at UCG, but we would welcome a report on it.*

The requested information will be reported by the four sub-projects, DT, CSC, RPC, and GEM, at the meeting on November 22

ANNA: THIS IS WHAT WE WROTE IN THE UCG PACKAGE...NEED TO PROVIDE MORE DETAILS…ALSO THE RISK TABLE CAN BE FOUND HERE: https://docs.google.com/spreadsheets/d/1-k0HKO5-4KIRYLZ8ygH4k3Q5uB1x-y0wrIYw06mm9Ac/edit#gid=1917218622

Schedule Contingency

In general the schedules shown in the Gantt charts have embedded margin on the critical path, primarily on the activities planned for installation in LS3.

For what concern the DT the embedded margin on the critical path, spread over the on-detector electronics production (OBDT) and the assembly of the minicrates tasks, is larger than 12 months. Even for the most severe risk of having to redesign the OBDT board due to lack of components, the embedded margin allows to fully recover the delays with a moderate impact on the schedule (< 6 months).

Additional margin is included for the on-detector electronics replacement in CSC to be installed in LS2. This margin is sufficient because this upgrade is based to a very large extent on the refurbishment of the ME1/1 boards deployed during LS1. A very detailed project and installation/commissioning plan has been put in place for the refurbishment of the CSC on-detector electronics during LS2, including a few weeks of contingency. For the CSC readout boards being installed during LS3, there is ample margin embedded in the schedule to account for all the risks.

For what concern the production planning of the new detectors in the forward region, the overall schedule has sufficient margin (>6 months) in the production of RE3/1, RE4/1 and GE2/1 chambers and related on-detector electronics even if their installation is planned before LS3. The schedule for the installation of RE3/4-1 and GE2/1 are constrained by the time allocated for detector installation during YETS2021/2022 and YETS2022/2023, which is imited. The details of the installation sequence during the YETS will be defined in the next months and we are working with CMS TC to ensure enough access time is allocated. Depending on the access time and the level of the progress of each of the two activities (GE2/1 and RE3/4-1), the Muon group will reschedule and redistribute the installation of the chambers between the two YETS to optimise the completeness of the detector.
As regards ME0, although production is based on the same resources (work, module production sites, chamber assembly sites, warehouses and cosmic stands at CERN) as GE2/1 production, the schedule (both for GE2/1 and ME0) includes float sufficient to absorb delay in the construction of GE2/1.

In all Muon upgrade activities the mitigation strategies are to put in place multiple supplier contracts or to set up multiple production sites to be able to cope with potential production delays. Rigorous quality monitoring process will be applied so that problems are discovered immediately to reduce schedule impact and ensure that contracts with suppliers explicitly take into account mechanisms to deal with quality problems to minimize impact on the cost incurred by the project.
