Dear Andrea,

Thank you for your comments. Most of them have been implemented or noted (see revised version of the paper) and detailed answers are added below.

The paper is very nice and full of useful information. It is long but at this round of comment I will not try to suggest way to make it shorter. This does not mean we should not try later... → ok, open for suggestions.

Paper organization (last update on April 4th)

- The sub-sub-section 3.1.1, 3.1.2, 3.1.3, 3.1.4 are not needed. Their content fits very well one after the other without the need of a sub-sub-title. Minor changes are needed around rows 103, 124, 143 and 153 to compensate for the absence of the titles. → ok, content of Sec. 3.1.4 is removed.
- The text in rows 96-101 should be, eventually re-checked to avoid unnecessary duplications with what is described below (for example rows 104-107). There is no need of a new paragraph between row 97 and 98 → paragraph has been rephrased.

- The sub-sub-sections 3.2.1 and 3.2.2 are not needed. The fact that we have two ROCs is well explained in rows 185-187 and it is enough to start the paragraphs about PSI46dig (row 189) and the paragraphs about PROC600 (row 241) in the proper way (as it is now it could be already ok) to make clear that we are talking of one or the other ROC → ok

- No need to break and start a new paragraph between row 277 and 278 → ok

- There is no real need for sub-sub-section 3.6.1, 3.6.2 and 3.6.3. These three parts fit very well one after the other we no need for a dedicated title. → ok

- Section 3.6.1 text could be better organized. The text in rows 388-392 could be moved earlier, about row 384 and replace the sentence about "testing procedure is described below". → changed according to suggestion.
- The details about the different temperatures given in row 387 are a repetition of what is written in row 459. There is no need to write them in the introduction to the tests (unless ALL the tests are done at two temperatures but in this case the fact that only in row 459 this is reminded is misleading). → all tests have been done at two temperatures, text kept in introduction and rephrased in later appearance.
- The preliminary tests described in rows 394-404 and the tests described in rows 406-461 should not appear as "something" different and presented with different styles. In particular the "titles" of the tests in

rows 406-461 should be removed (and, if needed, the text at the beginning of the description of each test adjusted). → ok

- Moreover, the sentence "Before starting the testing procedure all modules were tested…" does not sound OK. There is no need to split between pre-test and test in a public paper. → changed to „at the beginning of the testing procedure"

- The sentence about rejected modules in row 414 has to be moved where the module grading is described. → ok

- Since, I guess, the threshold trimming is done by using the results of the S-curve, the paragraph in rows 416-422 and the one in rows 424-431 have to be coordinated better. One possibility is to swap them and explain that the iterative process for the trimming consists of repeating the S-curve measurements. In any case it is not clear in the trimming paragraph what is the observable used to iterate. → ok, has been improved. Order is kept.

- The details on how the threshold and the noise is extracted from the S-curve have to be moved from section 7.4 to the paragraph in rows 424-431. Section 7.4 can refer to this section later. → ok

- The gain and pedestal measurement described in rows 438-446 is repeated also in section 7.5. Can you move here the description or make an explicit forward reference to section 7.5 (as of now I am not able to judge which solution would be better) → shortened this part and added forward reference to section 7.5.

- Section 4 has to be removed since the statement of rows 510-512 is, correctly, already in the introduction. Sub-sections 4.1, 4.2 and 4.3 have to be upgraded to be sections. → ok

- Section 5 has to be moved before subsection 4.1 and 4.2 (not before 4.3, though): having the mechanics and service cylinders already described help a lot the description of the readout and power system. → ok, but kept mechanics before cooling.

- Rows 899-900 do not contain a good introduction to the whole FPIX mechanics sub-section since they describe only the FPIX disks (!). No introduction was present in section 5.1 . Think about removing all the sub-sub-section 5.1.x and 5.2.x. In particular 5.2.3 is really a short sub-sub-section. → agreed. Subsections have been removed and introducturay sentence joined with next paragraph.

- The text of sub-sub-section 5.2.5 has to be merged where the service cylinder mechanics is described since it completes its description → ok

- The text of the sub-sub-section 5.2.6 has to be moved where the disk mechanics is described: it completes its description. → ok

- The Pilot system deserves its own section. Not a subsection of section 6 (it does not even match with the title, to some extent). → ok

- Sub-Sub-sections 6.2.1, 6.2.2, 6.2.3 can be removed: the three parts fit nicely in a single section with, maybe, a bit of rewording at the beginning of each part. → ok

- The description of the TBM hub address should be moved where the TBM chip is described. (rows 1023-1027). → ok

- Section 6.3: the sub-sub-section titles can be removed and the time evolution of the FPIX integration, now described in row 1097-1104, can be distributed later: after line 1119 for the module integration to disks, after line 1153 for the integration of the service cylinder and the shipment (somehow rows 1149-1150 already repeat what is at the beginning of section 6.3 and that I propose to remove) → Kept at the beginning to be consistent with BPIX section, but removed repetion later.

- What is described in rows 1261-1267 was (partly) already described around row 402. A strategy on where this has to be described and proper (forward/back-)ward references have to be established → L1261-1267 have been shortened and backward reference to L402 added.

- Rows 1268: the threshold trim is already described in row 205: refer to that (or write the sentence assuming that reader know already what the trim is. → ok

- Section 7.5 has to be coordinated with section 3.6.1. For example the sentence about the use of the average slope per column (ropws 444-445) can be moved in section 7.5 (since it is more related to the detector operation and reconstruction). Instead what is presented in rows 1304-1308 should be anticipated as much as possible (section 3?) because it helps to convert Vcal into electron and many results before section 7.5 are presented as a function of Vcal. Moving this part is not a problem because the X-ray test is described in section 3. → ok. Description of gain calibration kept here. Result of Vcal calibration moved to section 3.

- The content of rows 1310-1319 can be moved later, when the results with the collision data are discussed (time alignment and resolution). Section 8 can start with the summary of the good channel fraction (starting from row 1320), followed by the description of the DCDC converter issue, the repair campaign and is consequences. A subsection whose title refers to the fraction of active channels could be introduced → ok

- The text of subsection 8.1.3 is not needed. The issue with the present PROC600 is described in the section where PROC600 is described, the issue of the cross talk noise and the consequences on the thresholds are described in section 8.2.1 and the measurement of the efficiency is presented in section 8.3.1 . Remove the text of rows 1386-1396 and, if

needed, add more details in the other sections where this is already described → ok. Subsection 8.1.3 has been removed.

- Section 8.2.1 describes facts and results which are not obtained with collision (or cosmic) data and, therefore, there is no need to delay it so much. This part has to be moved in section 7.4 so that we have described in a single place and in a compact form everything about the thresholds: how they are tuned, measured, trimmed, how they evolved with radiation and the issue with PROC600. → ok, content has been moved.

- Section 8.1 contains sub-sub-sections which have little to do among each other: time-alignment (which is done once) and the procedure to mask and recover bad channels. These two sub-sub-sections have to be de-coupled. → ok

- Section 8.1.1 should be completed with the statements about the alignment (now in rows 1310-1317) and its title should changed into something like "Detector calibration (or tuning) with first collisions". It fits well after the part about the fraction of active channels (see comment above) → ok

- Section 8.1.2 is the ONLY section which is purely about routine operation. Since it describes how unresponsive channels are masked dynamically (actually it does not but it has to be expanded (just a bit) to describe the Soft Error Recovery procedure) and, eventually, focus on the "stuck-TBM" issue as an annoying example (which requires a special treatment), this section can be moved "AS IT IS" at the end of the DAQ session (now 4.1) because it describes issues already introduced (TBM sensitivity to SEU) and that are addressed only with DAQ/power tools. In this way we avoid long range forward/backward references → Tryed it, but does not fit well there, in particular because the power system is not introduced yet. Kept it in the operations section for now, but can be moved later. Could also decide to remove this section.

- Section 8.2.2 and 8.2.3 can be moved into section 8.3 (whose title could be changed slightly into something like "Detector response and performance monitoring"). → ok

- Section 8.3.3 should be moved as early as possible in the section about detector response and performance monitoring. Being before 8.2.3 helps to understand the LA dependence on the luminosity. The title of section 8.3.3 is not very meaningful. The sensor bias does not evolve by itself. We are showing the results as a function of the bias voltage at different level or irradiation. → ok

- Remove the break between lines 1528 and 1529 → ok

- Add a paragraph break in row 1538 at the sentence "The sensor properties…". → ok

- Section 8.3.4 can be merged into section 8.3.3 (and moved together with it). In this way some statements about FLUKA and the Hamburg model can be unified. → ok

- Section 9 has to be removed. I guess that 90% of what is described in this section (motivations, strategy, analysis technique, performance,…) are already in the Nuclear Interaction paper. The only parts which have to be taken are: the fact that we have repeated the analysis with the 2018 data, that we have obtained the results shown in figure… (choose only two figures, my suggestion is figure 57 and the left plot of figure 58) and that the beam pipe position is … as expected after the adjustement of his position, that the tight tolerance between L1 and the beam pipe is visible and that the two halves of BPIX are nicely overlapping. All this can be moved at the end of section 6.4 as a conclusion of the installation. This is because, presently, the results of the Nuclear Interaction analysis are not providing anything more than a confirmation of the positions of the different parts and this matter mostly for the installation. → ok, done as suggested.

What is missing and has to be added to the paper (last update on April 5th)

- CMS coordinates system has to be described as soon as possible in the paper, as it is done in the CMS papers. This will allow us to continue to refer to it in the rest of the paper (as we already do) → Coordinate system is defined in footnote 1)

- Module local coordinate system has to be defined as soon as possible when the modules are described. This will allow is to continue to refer to it in the rest of the paper. → ok, added at the beginning of Section 3.

- Every time we explain why the number of layers and disks have been increased by one, we have to remind that this is done to increase the redundancy of the detector (in particular for the HLT). For example in row 17, 42, 43 → ok

- Around row 57 it has to be reminded that this scheme is needed also to allow detector maintenance and refurbishment also during the short shut down during the Winter break (this will be proven when the replacement of the DCDC converters done in 2017-2018 will be discussed) → ok

- In table 1 the titles of the columns in the BPIX section are missing → ok

- In table 1 the z and RADIAL position of each FPIX INNER and OUTER disks should be quoted. The FPIX table should have six rows, one for each inner and outer disk, and one column more with the radial position. → ok

- Somewhere in the paper (for example in the introduction of section 3) it has to be reminded that the FPIX modules have an important difference with respect to the previous pixel detector: the modules are tilted mostly

in the rz plane to achieve charge sharing and that the pixel orientation is with the long side along r, different from the previous detector. This can be done around row 89 where (implicitly) only the BPIX module orientation is explained. → ok, added at the beginning of Section 3.

- In row 151 we have to give at least a hint about the specifications for the FPIX sensors. Is there a reference? Can we refer to the Turkish paper? → Since the sensors are the same as for the Phase 0 detector, we can use: K. Arndt, et al. Nucl. Instr. and Meth. A, 511 (2003), p. 106 (I don't think the alternate guard ring stategies we tried and discarded for phase 1 were ever formally written up and published, and they likely won't ever be now because they were a Gino Bolla project.)
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- Something has to be said or a reference has to be added to remind about the effective type inversion when the sensors are irradiated. This should happen either when the comment about the n-in-n approach ensure high E field close to the pixels after irradiation (row 111-112) or when the signal loss is described (subsubsection 3.1.4) → added comment around L111.

- Close to line 157 an approximated value of the detection threshold(s) should be provided to guide the reader → Sec. 3.1.4 is removed.

- In section 3.2.1 the expected hit rate in BPIX L2 (assuming that this is the largest experienced by PSI46dig, otherwise FPIX inner disk) should be reminded (and compared to the figure quoted in row 235, with the usual caveat that X-ray hit rate is equivalent to a more pessimistic particle hit rate) → ok

- Explore the possibility to add a statement about the ROC and TBM chip wafer probing and the resulting yield. It would make the paper more complete and it can fit in one sentence. → Added: „ROCs and TBMs were probed on wafers before dicing, the yield was 93% and XX%, respectively.

- Around lines 210-212 we are missing the description of the fact that there is a CMS level 1 trigger decision which is transmitted to the modules. The word “trigger” is introduced all of a sudden and used in a jargon style. To be seen if it is relevant to explain what happens IF a trigger does not arrive, eventually. → rephrased.

- In rows 298 and 300 we have to write what is the setting actually used during Run 2: enabled or disabled? → replace: "An automatic reset was added in order to send periodic ROC resets every N triggers, where N is a multiple of 256 times an eight bit setting." with:

  "An automatic reset was added in order to send periodic ROC resets every N triggers, where N is a multiple of 256 times an eight bit setting. Since the automatic reset also clears any stored data in the chip buffer, we decided instead to implement a 70 Hz reset signal sent to the pixels

during a dedicated LHC orbit where we wait 3000 bunch crossings with no triggers before the reset is issued in order to drain data in the ROC buffers."

- In section 3.5 nothing is said about the bump-bonding. See also the comment below about references about bump-bonding techniques. We should also remind that FPIX bare modules are not tested. →
- Add to the top of the section: „The bump bonding procedure relied on a more automated version of the process used by vendor RTI [ref0] for the original FPiX detector [ref1]. The yield for pre-production modules was 87\% and we felt that no bare module testing was needed for the production. We did though see poor, 30\%, yield during the early production. After investigation, it was determined that a change in the ROC dicing procedure, where photoresist mask was removed prior to dicing, implemented after the pre-production and prior to the production, left the ROC chips vulnerable to damage from chips created during the dicing process. The yield improved to 75\% after an inspection step was added by the vendor, rising finally back to mid-80\% or so, with more modules of the highest grade, after the change in the dicing procdure was reversed. Due to the poor yield in the early production, it was decided to perform testing of bare modules for the last 2 batches of bump bonded modules. Including the bare module test, with the possibility to rework rejected modues, the yield rose to above 90\%.
- ref0: https://www.rti.org
- ref1: P. Merkel, Nucl. Instr. and Meth. A, 582 (3) (2007), p. 771

- As already suggested above, section 3.6.1 should already contain the information about the Vcal to electron conversion factor because: it is measured with the X-ray test which is in section 3.6.1, and it is important to understand the results about the threshold and the noise which are also in section 3.6.1. Also its dependence on radiation should be described briefly because it may be relevant when the signal and threshold evolution vs luminosity are shown. → added at the end of section 3.6.1 when the X-ray measurements are discussed. For the evaluation with radiation there is a comment in the section where the plot is shown.

- Figure 16: does the BPIX trend plot include also layer 1 modules? From the position of the dashed line (lower than 1184) I would say that it does not while, instead, it has to. → The figure does not contain L1 production, which was a relatively small enterprise happening on a different time-scale. This is now mentioned in the text and caption.

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- In rows 535-537 it has to be said that FED, pxFEC, tkFEC are FC7 boards with different, custom, mezzanines. A reference to FC7 boards (L1 trigger upgrade or reference therein?) has to be added. → ok

- Rows 580-582: are we missing gatekeepers and LCDS among the components which populate the FPIX port card? Or do they not exist for FPIX? Sorry for my ignorance. → they do exist. Have been added.

- Section 4.2 is missing the description of the HV part: we have to remind at least the granularity, maximum possible HV (and remind that we are planning to upgrade it to 800V) and maximum current per channel →

  After line 695, add: "Each A4603D power supply module features four independent high voltage channels, able to deliver a maximum voltage of 600V and a current of 20mA. Depending on the layer, three or four pixel modules are supplied together from one HV channel. During LS2 the power supplies will be upgraded so that a maximum voltage of 800V can be delivered."

- Section 4.2 is missing the description of the LV power system for the auxiliary electronics and the control rings. Briefly we have to remind about it, the LV value, the power supply models (because we do that for the main power system). →

  New paragraph at the end of 4.2.3 (after the new HV part):
  "The electronics components on the service cylinders and supply tubes, including AOHs, DOHs, and CCU chips, require a supply voltage of 2.5V. This supply voltage is delivered by A4602 CAEN power supply modules in a direct powering scheme."

- In row 693 we have to write explicitly if we have run with the slow sensing enabled or not, eventually. →

  Change:
  After "1-2 seconds." Add new sentence: „The slow control loop was shown to work very well and was therefore always enabled during the operation of the detector."

- Add in row 698 the luminosity integrated at that time (about 30 fb-1 if I recall correctly) and the dose accumulated by the converter at that time (about 1 Mrad if I am not mistaken). →

  Change:
  30fb-1 is roughly correct, but I estimate a dose of rather 0.6Mrad, which is not quite consistent with the lab tests. So I suggest not to be too quantitative.
  After "irradiation campaigns" in line 706 add: "Failures similar to those seen in the CMS pixel detector were observed when disable/enable cycles were performed on the DC-DC converters during the irradiation, with a minimal dose to failure of about 1Mrad. This is consistent with

the dose accumulated by the pixel DC-DC converters by autumn 2017."

- In the introduction of section 4.3 (row 720) it has to be described what are the advantage of the 2-phase CO2 cooling: low mass, efficient heat exchange because it is two phase, simple: temperature is controlled only by the pressure in the accumulator,… → added after L722

- In section 4.3.2 we have to remind which pressure values operating at -23 C and at 15 C correspond to. This will make more clear to reader statements which appear later in the paper about the fact that the system has to run at "high pressure". → added figure with pressure range

- In section 4.3.2 (or in any case somewhere in the cooling section), it has to be reminded the target vapor quality value (range) at which we would like to operate the detector and we have to remind the flow values at which we have operated the detector cooling loops. → added statement about vapor quality. Discussion of flow is in section with mockup.

- Around rows 805-806 we can say that based on the results of that test during 2018 run we have reduced the flow in some BPIX cooling loop and gained 0.x C in temperature. → ok. Went from 2.5g/s to 1.8g/s and gained about 1C

- In section 5.1.1 we should remind that the ladders are alternated at smaller and larger radii values compared to the average values. This could be useful to understand how critical is the rate and radiation effects on the innermost L1 ladders. A picture/drawing like the one in the TDR could be useful. → ok, added text and drawing.

- In section 5.2.1 the explicit information about how many cooling loops are present per FPIX disks (either the inner+outer disk pair or inner and outer disks separately) should be added. I think that it is trivially one cooling loop per half disk, both for inner and outer. → ok, added. It is two cooling loops per disk, one for the inner, the other for the outer assembly.

- Around line 973 the power dissipated in the test figure 33 refers to, has to be indicated. → to be followed up.

- In section 6.1 it has to be added that the pilot system was used also to test the novel DCDC converter based power system (noise, SEU sensitivity, …) and that some DCDC converters were connected to dummy loads (and some moduled were NOT powered with DCDC converters) →
- Change:
- After line 1008 start new paragraph:
- "The pilot system was also used to gain first experience with the new DC-DC conversion powering system. Six prototype DC-DC converters were installed. One pair of DC-DC converters was used to power four pixel modules, while the other four pixel modules were powered directly

from the power supplies. No differences in performance were seen. The four remaining DC-DC converters were connected to external, passive loads, which were located at the power supply racks. The output voltages of these four DC-DC converters were monitored for signs of single event upsets, such as power glitches or spikes. No such events were observed. The problem with the DC-DC converter chips described in Sect. 4.2.4 was not found, as the critical cycles of disabling and enabling were not regularly performed."

- Around row 1028 we should add that thermal grease was used for the layer 1 module installation → ok

- Around line 1202 we have to write that, eventually we had no issue during the 2017 because of the leak reported above and that the leak was not observed again when the cooling connections were tested again after the 2018 installation (I guess…) → replace: "No channels were lost due to the installation." With "No channels were lost due to the installation and no effect on operations was seen due to the leak at 50 bar, nor was a leak present when the detector was re-installed in 2018."

- At the end of section 6.4 it has to be said that the same detector insertion procedure and verification was adopted before the 2018 run after the DCDC converter refurbishment and no problem was experienced, confirming that the procedure is well established and reproducible with very little unknowns (or something like that). → ok, added.

- In line 1208 if we want to keep the comment that the tests are done at +17C before lowering the temperature set point we have to explain why: to operate a low temperature the Tracker volume has to be sealed that this does not allow us to intervene on the patch panels if the tests reveal problems that can be fixed in that way. → Comment is removed.

- Can we add a trend plot of the fraction of (in-)active channels at the end of section 8 (around line 1343)? I would give a try to see how it looks in the paper. Not a strong suggestion, though. → To be followed up. Noted.

- Around lines 1381-1382 we have to remind that in 2017 the TBMs were power cycled by disabling the DCDC converters and that in 2018 we decided not to do it anymore to avoid to break them → ok.

- In section 8.2.1 the logic behind the threshold choice and setting is not described. Nothing is said about what happens when the threshold is set too low, for example. If we want to avoid too many details the CRAFT paper can be referred to, since it contains all the details (assuming that the process remains conceptually the same). → Added: "Thresholds directly influence the position resolution of the pixel detector. The lower is the threshold, the more effective is the charge sharing resulting in a better position resolution. Therefore the threshold should be as low as

possible but not lower. With too low thresholds pixel noise starts saturating the double-column redout and readout chips stop aquiring data. The strategy adopted is to adjust each readout chip to its lowest possible threshold, which results in a relatively non-uniform threshold distribution. More details is given in Ref[2]"

- In what is now section 8.2.1 (but that has to be moved and merged in section 7.4) I would add very briefly about the successful attempt, done at the end of the 2018 run, to reduce the L1 thresholds by xxx electrons (I don't remember the exact value: 500-1000) once we have reduced by software one of the main source of the cross talk noise (no need to go in more details than that) → Add at the end of this section: "In 2018 a better understanding of the detector and software improvmemnts suggested that layer 1 could be operated at lower thresholds. A test was made where the threshold in layer 1 was reduced by 700 electrons without any negative effect. This suggests that for the Run3 period we will be able to operate layer 1 with a significantly lower threshold than before."
-
- Around lines 1524-1528 it has to be said that the observables as a function of the bias voltage are shown at different value of the integrated luminosity. → ok

- Related to figure 53, the concept of the annealing has to be anticipated with respect to line 1547 and better explained: otherwise it is impossible to understand why the curves at different values of the integrated luminosity do not behave monotonically. It looks like the old module behavior measured at 51 fb-1 is less affected by the radiation than that of the new modules after 31.5 fb-1 and the reason is, I guess, the annealing of the old modules. When the annealing is introduced it has to be said very briefly that it usually happens in a (more or less) controlled way during the Winter technical stop by stopping the cooling → ok, added sentence.

- In section 8.3.4 (or wherever the text which is presently there will be moved) it has to be reminded that the leakage current can be reduced with the annealing (see comment above on when the annealing can be done) but we cannot exaggerate because of the reverse annealing. References are welcome. Highlight that the effect of the annealing is visible in the plots of figure 56. → ok, added sentence and reference.

- Around lines 1567-1568 we have to say something about the possibility to run during Run 3 without any issue related to the leakage current. It is enough to say that given the limits of the power supplies we see no problem to collect ~300-400 fb-1 during Run 3 (we can agree on a sensible value but it is not critical and the sentence can be turned into "no problem is expected during Run 3 when at most 300 fb-1 will be collected") → I am not sure that we should do this. This is a status paper and not an LHCC review where we have to preduct the future and speculate about rates and run duration.

- Missing references to be added
  - A reference to the TDR has to be added in the introduction. It has to be used to justify why a new detector is needed: higher hit rate: increase the bandwidth and reduce the dynamic inefficiency, more complex events because of the luminosity: increased redundancy (one extra layer), extension of the lifetime, … → ok
  - A reference for the n-in-n approach has to be added around row 108. At least we can refer to the CMS detector paper (even if in this case this reference can be anticipated ALSO to row 96) →ok
  - In section 3.4 (and 3.5) we should really try to find sensible references to the different bump-bonding technologies used by the different manufacturers → agreed. Some references added, some still to be added.
  - Row 389: is there a reference to pXar? Otherwise it is a bit pointless to refer to it by name. → added reference to Simon Spannagel's thesis
  - In section 3.6.1 (and later in section 7) reference to old papers where the module calibration procedures are described, should be added. For example the CRAFT paper, CFT-09-001, contains a good description of gain and threshold measurements. It is useful to remind the similarity of some but not all the procedures with the old detector. I don't know if there are other papers/proceedings/public notes which describe these testing procedures, even if they refer to the old detector and modules but are still valid for the upgraded one. → I agree that we can reference the CRAFT paper. I am not aware of any other. We added a sentence at the end of 3.6.1"

    "More details about the calibration procedure can be found in Ref[2]."

  - Also in section 3.6.2 a reference to the X-ray measurements done for the old detector could be useful (to show similarities and differences w.r.t. the old detector). The CRAFT paper can be used of the reference [18] in that paper. → added reference to CRAFT paper
  - A reference to microTCA has to be added in row 533 → any suggestions? Did not find a reference in the DAQ paper.
  - When the detector alignment is referred to (now at the beginning of section 8) the paper(s) that describe the alignment has to be cited. Even if they refer to the old detector the technique is the same → ok, reference added.
  - When the detector alignment is referred to (now at the beginning of section 8) we should remind briefly that the alignment procedure had to be repeated once more at the beginning of 2018, after the re-installation, at least for the large structures, the new modules and the modules that were recovered. → ok

- Around line 1428 a reference to the paper(s) were the pixel local reconstruction is described should be added. Probably TRK-11-001 is ok. → Added Ref[3] to the senstnce in line 1428 "Hit pixels are ...".
- References to previous papers where the Lorentz Angle measurement is described have to be added in section 8.2.3. In addition to reference [42] (THERE IS A MISTAKE, REFERENCE [41] AND [42] ARE SWAPPED!!) also CFT-09-001 (the CRAFT paper) and TRK-10-001 (the first tracker performance paper) have to be added. → We already reference the both documents in form of the JINST papers. It is much better to reference JINST than the internal CMS documents.
- Around lined 1472-1473 remind that the pixel detector is used also for the track seeding and put a reference to TRK-11-001 → Add Ref[3] and add " ... good pattern recognition (seeding) ..." "seeding is the same as "patter recognition".
- Around line 1499 put a reference to TRK-11-001 and to BTV-16-002. → Add Ref[2] at the end of the sentence in line 1499, Add also Ref[BTV-16-002].
- Around lines 1509-1513 references which describe the change of the electric field with the radiation and the increase of the trapping have to be added. → Add Ref[40,44] at the end of the sentence "Charge trapping ....".

Specific comments to the detector refurbishment and the reasons for that (last update on April 5th)

- In the introduction, in the paragraph which starts at line 27, it has to be stated the in the paper there will be also a description of the issues experienced during the physics run and the modifications that have been implemented during the 2017-2018 winter shutdown and that will be implemented during LS2. These issues and modifications are related to the readout chips, the DCDC converters, not flexible enough time adjustement, the power system and they will be described in the relevant section. With this statement we make clear to the reader that: 1) there will not be a section dedicated to issues and the refurbishment plan, 2) that in a few parts of the paper we will describe something which does not exist yet, 3) and that this part of our paper will not be described with an historical perspective (first the observations, then the investigation and finally the solution) to make the paper more compact. → ok, added statement in the introduction.

- In the lines between 169 and 177 we are addressing, more or less explicitly, the detector refurbishment for the first time. This part has to be made clearer. We have to start by saying that we care about the longevity (of BPIX layer 1) up to 300 fb-1 because this will be likely be achieved by Run2+Run3 and, maybe, in Run 3 only. Therefore our first action is to replace layer 1 during LS2 to “restart the counter”. Secondly, as shown in figure 6, when the fluence is large (2.8e15 is our example) the largest is

the HV bias the largest is the signal and, therefore, our second action is to upgrade the power supplies to reach 800V (and a forward reference to the power system section can be added). Thirdly since we had to operate with larger than expected threshold the BPIX layer 1 ASIC (forward reference to where the threshold are described), and the threshold is important (again figure 6 is there to demonstrate that), we have decided to design a new version of PROC600 that will be installed with the new L1 (forward reference to where the new PROC600 is described). Do not use words like "currently" or "presently" in this paragraph because they will become misleading in future. I would remove the statement that at 800V we will collect 10000 electron because this is not what is in the plot of figure 6 (and 10000 electron is not such a magic value). → this paragraph has been removed. The replacement of L1 is now motivated at the end of Section 2 by referring to the TDR. The replacement of the power supplies is stated at the beginning of the sensor section and the revised version of the PROC600 is in the ROC section. This avoids forward references.

- In line 257 replace the reference to section 8 to a text which explains that we have observed shortcomings for what concern the hit efficiency and the cross-talk noise. → ok

- In the line 262 add a forward reference to the section where the hit efficiency results are shown → ok

- In lines 278-280 add a forward reference to where the thresholds are discussed: now it is section 8.2.1 but this has to be moved and merged in section 7.4. It would be better to be a bit more quantitative on the possible threshold reduction with this changes. → This refers to v4, so I am not sure what the forward reference should point to.

- The description of the problem of the present TBM, now in lines 1376-1378 has to be moved in section 3.3: no need to write in section 3.3 that a new version is needed without explaining what is the problem. In section 3.3 it has also to be said what is the rate of stuck-TBM (for example in L1 0.7% every 100 pb-1, if I recall correctly) and they can be recovered only if there is a power cycle. The details about how the power cycle is implemented and the impact of these power cycles on the DCDC converters can be left in the corresponding sections → ok.

- Around line 311 add a forward reference to the detector time alignment section to justify why the delays are added to the TBMs → ok

- Line 467: I just want to flag a tricky issue: we can be asked to explain why we have not observed the issue of the present PROC600 dynamic inefficiency when we did the high rate test. In other words why the red line of figure 8 was not observed. The official explanation is that those tests were done with the reset (by mistake) and, therefore the orange line was measured. But we have to agree if we want to tell this story and what if we do not. → noted. To be followed up.

- The title of section 4.2.4 could be changed in something more specific and related to the DCDC converters since it addressed only that issue. → changed to „Issues with DCDC converters during 2017 operation
- In line 712 we should say briefly that we decided to change all of them because a much larger fraction than the broken ones were found having an anomalous response (or however you want to name it). In line 714 "at the time of writing…" can be removed → ok
- and in line 716 it can be added that the new version is expected to immune to the problem because it features a path for the leakage current. → ok
- In this section the sentences about the TBM can be simplified taking into account that the issue (but not the detail of how the power cycle is done) is already described in the TBM section. → ok

- A reminder: what is described in section 8.1.3 should be distributed in the relevant sections and the section 8.1.3 should disappear → ok

- Nota bene: in line 1405 there is a statement with the PROC600 cross talk noise is described in section 3.2.2 while, presently, this is not the case. As I have suggested the noise issue and the higher threshold issue should be described in 3.2.2 and in 7.4 where 8.2.1 will be moved and merged. → ok

Statements that have to be improved (last update on April 6th)

- Line 16: stating that the detector is able to cope pileup 130 with 25 ns bunch spacing means that it can cope with a luminosity of 5.2*10^34 cm-2 s-1 !! This is not what is written in the same sentence. It is true that it can cope with PU~110-130 and L1 rate of 100 kHz for what concern the bandwidth to readout the data from the detector to the central DAQ system, but the dynamic inefficiency will be very large if the bunch spacing were 25ns. Please check and eventually rephrase to make it consistent and accurate. → statement is removed.

- Lines 17-18 add "a FOUR hits coverage" otherwise it could be misleading. And check that it is true that there is a 4 hit coverage up to 2.5 → ok

- Line 68: replace the generic "existing infrastructure" to "the existing cables from the power supply racks to the Tracker patch panel inside the CMS magnet bore (or something like that). No need to not to be specific. → ok

- Line 74: "module connectors" is misleading. The reader could assume that they are the connectors on the modules and wonders how it is possible that they are moved away. → rephrased

- Lines 81-82 could be improved into something like: thanks to the new features described above (more layers, lighter, closer to the beam, able to cope with higher particle rate), the Phase-1 pixel detector (is expected

to?) has the same, or even better performance of the original detector at twice as large luminosity. If not added before, here a reference to the TDR fits nicely. → ok, reference to TDR is added now on L15.

- Line 85: it has to be specified that it "uses a similar module design as the original detector BPIX modules" (the FPIX module of the new detector are more similar to the BPIX modules of the old detector than to the FPIX modules of the old detector). → ok

- Line 101: which "requirements"?? → to be used in the detector. Rephrased.

- Line 116: the double sided processing is needed not because the n-substrate is used but because the n-in-n design is used. → rephrased

- Line 120: replace the start of the sentence with something like: "silicon sensors that collect electrons on the segmented electrodes [the pixels] require an n-side isolation". Also the holes are collected and the sentence as it is now would not be accurate → rephrased

- Line 200: "analog performance" sounds too jargon to me. Can you find anything better? → rephrased.

- Line 217: "the buffers" means that they are introduced before, but they are not. Can you introduce them when the timestamp and the pulse-height information readout is described above? → ok

- Line 221: replace "services" with "optical links" which is what matters this time. → ok

- Line 223: I would add "CONSEQUENTLY an 8-bit successive approximation ADC…" → ok

- Line 227: I am not sure but we have to decide if "time walk" (which is a pretty generic term in English) is clear enough. In the CRAFT paper it is briefly described and eventually there is reference [7] which happens to be reference [8] in our paper. Can we, for the moment, at least add reference [8] just after "time walk"? → added reference

- Line 238. It has to be indicated the luminosity (or pileup) at which we expect less than 2% losses. → ok, added @ 120 MHz/cm2

- Line 249: the statement "three pending column…" should be in the PSI46dig section and just reminded here → ok

- Since in lines 266-268 there is no reference to "full time stamp buffer" it is not clear if and how the statements in lines 264-266 are linked to the ones in lines 266-268 → It is all correct. At hight rates the problem appears when the buffer is full. Maybe rewrite the sentences "At high

rates ..." with " This can often happen at high rates. If a coincidence of going back to acquisition mode and a new hit in a pixel occurs it can generate...."

- In line 272 it has to be said that the periodic reset fixed the inefficiency at low luminosity but not the one at large luminosity (forward reference to the section with the efficiency measurement results). → ok

- Line 296. “buffered triggers” is jargon. What about “buffered triggered event data” or “buffered data of the triggered events” → ok

- Line 320. Add “The HIT rate in L1 required…” → ok

- The title of 3.6.1 and line 405 should be changed in “module functional tests” in my opinion → section header 3.6.1 is removed, L405 rephrased.

- In line 385 and 484 the use of the term “electrical tests” is misleading because also the other tests involve “electricity”. Look for a better way to classify them → used „functionality tests of ROCs and TBMs“ in L385 and „functionality test“ in L484

- Line 415: can you clarify if the result of the trimming is used to operate the modules once installed in the detector? If this is the case it could be useful to add it. If not, never mind… → yes, added in calibration section.

- Line 432: it is not clear if the PH optimization has an impact on the module grading or if it has to be considered as one of the preparatory tests and tunings described in lines 394-404. I am not suggesting to move it there but I am wondering if it could be clarified a bit better. Maybe once both the preparatory tests and the tests which are now highlighted with a title and an enumerator will be described with the same style, this would be less of an issue. → PH optimization is not used for grading, but as preparation for gain calibration. The two paragraphs have been merged.

- Line 437. I think that the statement “is optimized as a function of the injected signal charge” should be re-written into something like “is optimized by injecting signals with different charge amplitude”. Otherwise it looks like there is one optimal setting for each signal amplitude. → ok

- Line 441. It is not defined what “this curve” refers to. In line 440 a change like “and records the MPV of the pulse height distribution as a function of the Vcal DAC setting” Only in this way a “curve” is defined (MPV vs Vcal). → ok

- Line 445 : add something like “optimized PH MPV” → rephrased.

- Line 451: if the pad used to induce signal to the sensor is not described before (and I think it is not) then you cannot use “THE metal pad…” and you have to use “A metal pad…” → ok

- Lines 471-474. It is not totally clear to me, reading the text, why something special has to be done to identify inefficient double columns instead of, for example, comparing the efficiency of each pixel, obtained with the pixelalive test and look for clusters of inefficient pixels in the same double column. → the main target of the test is the efficiency of the double column-periphery. This will not be tested in a pixel alive test where one pixel at a time is injected.

- Line 479: is it the “mean value” or the “MPV”? → MPV

- Line 500 “cumulative production” should be modified in something like “cumulative production timeline/profile/evolution”. → rephrased

- The problem of the FPIX module noise in lines 504-508 should be described better: calling it a cause for failure seems to indicate the the modules with this problem were NOT installed and they are not among the 816 accepted for installation. But then the sentence about being fully recovered after 10 fb-1 indicates that some of them were installed and therefore they were not only among the 816 but, eventually among the 672 that were installed. → rephrased.

- Line 530: I think that the CCU I2C channels are NOT used to program ROCs and TBMs and, therefore, writing “the readout electronics” can be misleading. “PIA” has to be defined (later in the paper it is called “parallel interface” if I am not mistaken in row 659) → added „on the service cylinders“, PIA now defined and used also on L659

- The “pixel specific modified I2C protocol at 40 MHz” (line 520 and in many other places) should not be referred with the term “I2C” because, I think, it is not derived from I2C (ask Wolfram). The use of “pixel” ad an adjective is jargon. What about a/the “custom 40 MHz communication protocol”? To be checked in several places in the paper where, sometimes, it is indicated only as I2C protocol at 40 MHz (which is wrong). → In terms of logic the protocol follows i2c standards. The difference is electrically and the frequency. Therefore the term „pixel specific modified i2c protocol“ is ok and used now consistently in the paper (also in the TDR it is called „high speed i2c protocol“)

- Line 533: it is not clear between what the 10 Gb/s links are → added „to central DAQ“.

- Line 540: “groups of ROCs” should become “pairs of ROCs”. In any case what is in line 540 and 541 has been already described when the TBM was described and can be removed or made simpler: just remind that there is a 400 Mb/s stream of data from the TBM. → ok, simplified.

- Line 549: are we sure that new fibers were laid down? My recollection is that no new fiber was deployed between the counting room and the patch panel (and this is how I interpret what is written in line 549). But I can be wrong → This comes from Jan Troska. The optical fibers between PP1 and PP2 are the same, but additional fibers were laid in between PP0 and PP1.

- Line 576: clarify that the delays in the LCDS are adjustable (in hardware) but not programmable. Otherwise the reader would wonder why we do not use them to fix the timing issue. → ok

- Line 584: the "power boards" were not defined before. What are they? → removed.

- Lines 583-585. The forward definition of the service cylinders can be avoided if/when the section about the mechanics is moved before the section about the readout system. This part has to be modified either way. → ok

- Line 653: the term "another PCB" is too generic. What is the name of this board? → changed to: along an extension PCB to the detector modules

- Line 661: strictly speaking saying that the status signals are "combined" is not enough. Is it an OR? An AND? I know that actually is more complicated than that… →

  Change:
  In line 661 after "combined" add „(logical OR)"

- Line 672: is "complex" the right word or, instead, something like "more demanding" is more appropriate? →

  Change: remove the word "complex", but do not replace with "more demanding", as this is also not quite right.

- Line 694: of the fast sensing has to be mentioned it has to be explained what is it for. At which value the output voltage is set to by the fast sensing? Is it in alternative to the slow sensing when the latter is enabled? →

  Change:

  Remove the sentence "A fast sensing is still implemented at the power supply backplane."

- If we need the short introduction of section 4.3 I would try to pass the following message: "in a detector based on silicon sensors the cooling system has two purposes: remove the heat produced by the readout

electronics (and the sensors) and keep the silicon sensors at a temperature low enough to mitigate the effect of the radiation". "but also" sounds odd to me. → changed to „and"

- Lines 724-728. I would rephrase with the CMS detector as subject: "CMS phase-1 pixel detector cooling features the 2-PACL approach which was developed in Nikhef for the AMS and LHCb detector…" → ok

- Line 734: I would write the other way around "it evaporates because it extract the heat produced by the electronics" (unless I missing the fact that, in English, "extracting" can indicate the cause and not only the effect). → ok

- Line 757: using "on-detector cooling" as a synonym of "detector cooling loops and interfaces" is a bit too short. To be improved. → ok

- Line 762: clarify that "one half of the detector" means FPIX or BPIX. Highlight that the two-plant solution allows us to use different temperature set points if we would need it (but we don't). → ok, added.

- Line 796: being able to extract more power (18kW vs 11kW) at -23C when in backup mode sounds odd if it is not justified. Is there a simple explanation? (Maybe I was told and I forgot) → Answer:

  When we were running in back-up, the limiting factor was on the CO2 side (heat exchanger) but when we were running in normal operation, the limiting factor was on the main chiller. This is why we have "strange" values and not 2 times 18 kW in normal operation. The chiller could not take more than 22 kW in total (on top of the full C6F14 cooling of the Tracker).

- Line 791 "upstream services" to be changed into something like "services the cooling system relies upon" → ok

- Line 800: explain that it is an evaporative CO2 cooling plant → ok, added

- Line 804-805: the fact that in real life, because of the pressure drop, the temperature can decrease along the cooling loop should be anticipated already in section 4.3.1 as a deviation from the ideal model. Here we can just remind the quantitative result. → prefer to leave as is.

- Line 813: is it true that the cooling pipes are the backbone also for the FPIX disks? → rephrased

- The title of section 5.1.3 could be misleading since there is already a cooling section. → changed to „BPIX cooling lines"

- Line 858: it should not sound as if it is the first time we announce that we use CO2 cooling. Therefore the sentence should be rephrased into something like: “because 2-phase CO2 cooling is used, then…” → removed

- Line 864: those or not “cooling loops” they are “cooling segments” or something like that. They become a loop once they are connected together. → ok

- Line 909: quote the inner diameter as done for BPIX → ok

- Line 993: explain “access” to what → ok

- Line 995 “incorporating” sounds off → rephrased

- Line 996: it looks misleading to me: reading this line I have the impression that the mechanics of the third disk has always been present in the old detector and only recently it has been equipped with the modules of the pilot system. → rephrased

- Line 1000: change into something like “before the installation the pilot system was commissioned at a test stand…” → ok

- I think that the text of lines 1001-1008 should be re-organized a bit. The message to be passed is that “the commissioning of the pilot system before the installation and the operation of the pilot system during the 2015 and 2016 run helped us to: improve the design of the TBM, complete the FED f/w, test the DCDC converter SEU sensitivity in the LHC environment, … More details can be found in [12]. Everything has to be turned into a positive message more than a list of problems (eventually addressed). → ok, rephrased and more details on the findings with the DCDC converters added.

- Line 1052: is it a coincidence that the number of optical fibers is identical to the number of modules? → it’s wrong. Should be 1984 fibers.

- Line 1083: clarify if the number of dead channels quoted here are in addition to the ones reported at the end of the installation of the modules on the mechanics → ok. Said in next sentence.

- Line 1115: I think that the fact that two screws are used to hold the modules have been already said when the mechanics is described → rephrased, but kept

- Line 1128: what does “integral DCDC converters” mean? → removed.

- Line 1132: using outer and innermost in the same sentence, one w.r.t. the radius and one w.r.t. the longitudinal axis is confusing. If the installation sequence has to be described it has to be described more clearly. → replace: "Completed half disks were lowered in place using a special

manual crane and holding fixture. The outer half disks were installed first, with the innermost half disk installed first."

With:

"Completed half disks were lowered in place using a special manual crane and holding fixture. Installation of half disk pairs proceeded in order from the larger radius half disk closest to the interaction point followed by the smaller radius half disk, until all 3 half disk pairs were installed and cabled to port cards."

- Line 1133: is it “half cylinder” or “half disk”? I guess the latter. → half disk
- Line 1137. If we want to describe the problem of the cable length, then it has to be made clear how many half cylinders were affected. From the text it is not clear →rephrased.
- Line 1140: was the read-back capability of the ROC ever described before? If it has to be mentioned it has to be said what can be read back. → removed
- Line 1146: if we want to keep the sentence about the calibration, we have to add a forward reference to the calibration procedure. We can also, instead, add later, when the calibration is described, that some half cylinders were tested both at FNAL and later at CERN, to avoid too many forward references. → removed comment
- Line 1165: “transfer lines connecting to the CO2 cooling plant” sounds like the whole segment from PP0 to the cooling plant was installed at the beginning of 2017. Instead only between PP0 and PP1 was installed at that time while between PP1 and the cooling plant the installation was done during LS1. Please clarify → want to avoid introducing PP1. Slightly rephrased.
- Line 1175: “mockup of the installation area” should be replaced with “mockup of the volume where the pixel detector has to be installed” → ok
- Line 1189: no need for a public paper to use different words like cartridges and jumper rails for something that, in case of BPIX was named differently: installation boxes and temporary extension rails. → ok
- Line 1192: I am wondering if “in the direction transverse to the beam” is proper and clear enough → it refers to overlap in x, so it is correct.
- Line 1220 : this is NOT I2C communication, at least not the one toward the module, right? See comment above about the 40 MHz custom communication protocol. → removed I2C

- Line 1236: I would replace FED input with FED connector otherwise we give the impression that the FED has only two inputs while it has 24 → ok

- Line 1244. Since the TBM delays have been already introduced the sentence should be changed into something like “The TBM delays have to be adjusted to synchronize the ROC readout data at 160 Mb/s with the signal transmission speed of 400 MHz” → ok

- Line 1321: is “infrastructure” the right word to be used here? → changed to „issues with individual BPIX readout and power groups“

- Line 1350: the time walk is due to the amplifier but also the comparator (check with H-C) → removed word „amplifier“. No need to state it here as time walk is mentioned in ROC section.

- Line 1357-1359. The new features of the delays in the new TBM has been already announced. Change the sentence in a way that reflects that: “The functionality of the phase adjustement in the TBM will correct this feature…” → ok

- Figure 47: can we justify why the new layer 1 modules have different thresholds? We have to explain that → This all explained in a whole paragraph in linew 1403-1406.

- Lines 1464 and 1465. Can we remove “mostly”? One method is used for BPIX and one for FPIX, no exception, I guess. Explain that in FPIX a different method has to be used because we do not have shallow angle tracks. → ok, removed

- Line 1467: the luminosity is “collected” not “measured” → ok

- Line 1481. The subtle difference between “pixel hit” (only one pixel) and “hit” (line 1474) as the full cluster is not well described in this section. We should improve it a bit → improved this part.

- Lines 1489-1490: the fact that there is the reset cannot be ignored when the low luminosity efficiency being above 99% is commented. Something like “in L1 the measured efficiency is not affected by the PROC600 issue at low luminosity because of the periodic reset while at high luminosity…” → ok, added.

- Line 1505: we cannot simply say that the width is referred as the resolution because there is no way to judge the absolute value. We have to say that even if the width depends also on the residual misalignment and partly on the resolution of the other two layers, MC studies and approximated analytical calculation shows that it is proportional to the resolution with a proportionality factor given by … (and we can use recent Danek’s studies). Otherwise the alternative is to quote MC results and show that we are not that far. → Replace the sentence "The width is

then referred to as the resolution." by "The width of the residual distribution is related to the hit's position resolution (called sometimes "point" resolution) of the layer under study but also includes contributions from detector alignment and the accuracy of the measurement of the hits in other layers used for the track extrapolation. The second effect can be taken into account by multiplying the width by sqrt(2/3), assuming that all layers have a similar position resolution. The contribution from alignment is harder to estimate. Monte Carlo studies show that its contribution is below 5um, which should be added in quadrature to the "point" hit resolution, and is therefore quite small. For example the fit results for layer 3 from Fig.52 are 9.5um in the r-fi direction amd 22.2um in the z direction. Applying the correction of sqrt(2/3) one obtains 7.8um and 18.1 for the two directions respectively. This is very close to the resolution obtained in MC studies by comparing the simulated and the reconstructed hit, which are 7.3um and 18.1um respectively. As a simplification the width of the residuals distribution is used to monitor the position resolution in time and to compare the various detector layers."

- Line 1515: the starting value of 150 V does not appear in the table 2 !! → changed to 100V

- Line 1516: isn't the difference due to the fact that in BPIX it is better never to exceed with the HV setting not to spoil the charge sharing? → I fit wasn't for the issue discussed in section 3.5.3 the FPIX sensors would also have been operated at 100V

- Line 1525 and figure 53. I think that the right figure should be described first so that the full depletion voltage value is presented to the reader before the comment about the efficiency being close to 100% before the full depletion. → I do not understand. The sentence says that 100% efficiency is reached at a voltage below the full depletionvoltage? Do we really have to explain what the "full depletion" voltage is? It is quite a basic concept related to silicon sensors. Maybe a reference to [44] is enough.

- Line 1539 (and before). When the concept of the periodical adjustment and of the optimal value are described, it has to be explained that the chosen value should be such that efficient charge collection is ensured at least until when it is possible to update the value and have the new calibration computed and deployed. → I really do not understand what ot brings to the non-CMS reader. This is a purely operational consideration.The important message is that one has to increase the bias
-
- Line 1541: I would replace "predict the depletion voltage" with "predict the charge collection" → ok

- Line 1545: we should clarify that the Hamburg model predict the effective doping concentration which is converted into a depletion voltage with a simple model → Add after the sentence "The model fits ...." the following:

  "Note that the Hamburg module uses very simple formulas for the depletion voltage, therefore its predictions are not suppose to be very accurate."

- Line 1548: more than “this was planned since the beginning” I would write this is one of the main feature of the n-in-n sensor concept. → ok

- Around line 1557. I would re-organize the concepts expressed here in this way: the leakage current as a strong dependence on the temperature and, therefore, to avoid, eventually, thermal runaway and/or power supply trips, the cooling has to be efficient and the absolute set point chosen properly. → I do not see what is different in this formulation and what is written?
- Line 1563: comment that also the effect of the annealing during the shutdowns and technical stops is reasonably well simulated . → This is already taken care off by another comment.

Statements and figures about radiation (fluence and dose) (last update on April 23rd)

- In general: whenever it is possible references have to be cited when values of fluence and dose are quoted. This is more important when they are not consistent with the phase-1 pixel detector upgrade TDR and with the phase-2 tracker upgrade TDR. → added citation to FLUKA.

- Lines 79 and 229-231: does it correspond to 300 fb-1 or 500 fb-1? According to the figure 9.15 of the TDR it looks like 120 Mrad are reached for 500 fb-1. But it is not easy to judge. → numbers are now based on FLUKA. 100Mrad for 300\fb, 180 for 500\fb.

- Lines 159-160: 2.8*10^15 neq cm-2 seems to be too pessimistic for 300 fb-1. In the TDR (bottom of page 116) 3*10^15 for 500 fb-1 are estimated (1.8*10^15 for 300 fb-1). For the phase-2 TDR studies I remember we quotes something like 2*10^16 for 3000 fb-1. Can you verify and eventually justify this figure? If one of the reasons for a more pessimistic figure is the fact that the innermost ladders of layer 1 will experience a significantly larger fluence with respect to the average radius, my suggestion is to quote in table 1 two values for the radii of layer 1: the radius of the innermost ladders and the radius of the outermost ladders, properly explained in the text → The paragraph is removed. Now added a table with expected fluence/dose from FLUKA. For L1 the difference between inner/outer layer is up to 20%. For now kept just one value for

L1 in the table and added a comment after the mechanics is introduced. This is to avoid introducing the staggered ladder arrangement already at this point (but can be changed if desired).

- Line 977: it quotes a reference: can it be used for the other lines where the TID is referred to? Is it consistent with what has been quoted for the BPIX? Is it consistent with the phase-1 TDR? I am ok if we want to change with respect for figure 9.15 of the TDR but a sensible reference is needed. → removed this part, after introducing table with fluence estimates.

- Table 2: The fluence values quoted for Layer 1 are not consistent with the statement in lines 159-160 about 2.8*10^15 cm-2 at 300 fb-1. They are closer to ~2.1*10^15 cm-2. The ratio of layer 2 and layer 1 fluence is not close to 4, the value we are used to. It is closer to 5: is it justified by a reference? If this is explained by the different fluence between the innermost and outermost layer 1 ladders, I would quote two values for layer 1 (as it is done for FPIX). Furthermore, there are too decimal digits in that table: we do not know the fluence with that accuracy. This table should also be corrected to consider that FPIX ring 1 was biased at 350 V but not FPIX ring 2. I suggest to split FPIX in two columns. Furthermore, the table says that the starting bias value of BPIX was 100V while elsewhere in the paper (line 1515) it is written that it was 150 V. Is it possible to indicate in the table when 2017 ends and 2018 starts?

(a) The fluence numbers have been modified to reflect the fluence values obtained from FLUKA. The factors for layer 1 are 0.725, 2 0.175, 3 0.0868, 4 0.0513.

(b) I think splitting layer 1 is an unneccesary complication. These numbers are approximate anyway.

(c) Numbers have been rounded to 1 digit

(d) Prefer to have comment about change to 350V in FPIX ring 1 instead of adding additional column

(e) The operating voltage was always supposed to start with 150V, this is why the text often says 150. Due to a DCS mistake we started with 100V. Changed in line 1515 150 to 100V.

(f) The 2017-18 split is now indicated in the figure caption: "The rows up to 51.0fb-1 correspond to the 2017 running period, the last 2 rows are for 2018."

Units (last update on April 23rd)

- Use consistently in text and plots rad or Gy. “rad” has to be spelled lower case (lines 79, 976, 977, 980, 982, footnote 8) → ok, use Mrad
- Table 2 caption: “cm-2” is missing when the unit is described. → fixed
- “Gbs” to be changed into “Gb/s” in line 533 → ok

Analyses (last update on April 23rd)

- The analysis of figure 49 has to be improved as known by Tanja and Irene. We should not forget to update this plot before submitting the paper → added note in paper so that we don’t forget.
- The analysis of the position resolution (8.3.2) has to be improved is some way because, presently, it does not produce an absolute value of the resolution. Either we explain how to convert (roughly) those values into absolute resolution values (see recent Danek’s studies) or we compare to the MC. → The resolution point is taken care by the changes proposed for "line 1505".
- The top right plot of figure 53 and the plot of figure 54: we have to be sure that the different value of the plateau position is not due to a non-corrected drift of the gain calibration instead of a change of the charge collection efficiency. → This could be a problem but we do not have a safe method how to correct for it. One could apply the vcal change but this would not change the figures very much. Maybe a comment after line 1528 would solve it: "The exact calibration of the charge in electrons is not easy to obtain due to the fact that the injected calibration siganle also vary with irradiation. Therefore the absolute charge value is not precise and has an accuracy of about 10%."

Plots and figures (last update on April 23rd)

- Figure 2: there is a bit of unbalance between BPIX and FPIX for what concern the level of details. The details about BPIX service cylinders can be in figure 18. Many of the elements described in figure 2 have not been introduced yet (DCDC ,…) → Removed labels of sector content figure and now only point to BPIX/FPIX detectors and service cylinders.
- Figure 3: different eta region in the top and bottom plots is not nice. Can we add the curve of the original detector in the bottom plot and reduce the number of plots to 2 ? → yes. Noted. To be done.
- Figure 4: is it possible to add a cross section of a module which shows the sandwich made by rails, ROCs, sensor and HDI? A drawing which resemble the picture here: → ask Silvan https://cernbox.cern.ch/index.php/s/IQ7UtInGldjVPhO → yes, added (Fig. 8 in new draft)

- Figure 8: the line “v2 with resets” could be misleading because in the text we describe the 70 Hz reset. But the reset needed to achieve the good efficiency at high pixel rate for the orange curve has to be issued at every event. My suggestion is to remove it. → noted. To be followed up.

- Figure 9: the caption should explain that what is shown is the temporary cable → ok

- Figure 10: “BBM” should be explained → ok

- Figure 11: it cannot be “hit efficiency” because the scale goes up to 5. Maybe 5 pixels are injected with signal? → Figure has been removed.

- Figure 12: in one of the four plots the horizontal scale is not in Vcal units (top right). I think that all the plots should feature a horizontal scale in electrons (with the Vcal to electron conversion factor explained before in the text) → yes. Noted. To be done.

- Figure 13: the caption should explain which line is which. Furthermore, the points at low inject charge which are for included in the fits spoil a bit the justification for the tanh fit. Do we need it for this paper? Is it used anywhere in the rest of the paper? → removed tanh fit in figure and caption.

- Figure 15: x and y axis should be swapped. The pulse height as a function of Vcal is measured as a function of the X-ray signal (in electron). → noted. To be done.

- In figure 16 the separate lines for grade A and grade B for FPIX are not needed because in the text we do not specify if only grade A or A+B are installed (I guess the latter). Therefore the plot should contain “Received” and “A+B”. If grade A is relevant for the discussion about the modules with noisy sensors (but for the moment the paper does not link those modules with the grading), then also the grade A only line can be added, but not B only (or C). Clearly the BPIX and FPIX plots should be done with the same style → yes. Noted. To be done.

- Figure 17: should the box “PLL” become “TPLL”? Are the violet lines “fast i2c”, too? Or are they normal I2C? See my comment above about non-calling “fast i2c” the communication protocol for the pixel modules → ok, fixed.

- Figure 18: the letters to identify the sectors and the names of the components should be added → yes. Noted. To be done as soon as figure is updated.

- Figure 19: same comment as for figure 18 → ok, done.

- Figure 25: we have to find a way to have the data of those lines to create real plots and not just screen shots. → Figure is removed.

- Figure 33: It is not clear what "-4.2C" and "max 17.8" refer to. To be clarified or removed if not relevant → to be followed up.

- I think that figure 34 can be removed since "no significant change has been observed" → figure is removed.

- Figure 44: "August 2017" should be complemented with the amount of integrated luminosity at that time → noted. To be done.

- Figure 45: colors and styles should be changed to better see the three distributions. Is it possible to plot the "Gain" distribution (left plot) using electron/ADC as unit by using a default Vcal to electron conversion factor? Even if this is not what we measure explicitly, it is more interesting for an external reader. → ok. Done.

- Figure 47: can the two plots combined in one (2017+2018)? Can we have a similar plot for FPIX? Is the first L1 point (at about 2000 electron) relevant? What's its meaning? Can it be removed? → ok, noted. To be done.

- Figure 48: we have to inform about the luminosity collected when those distributions were measured and we have to explain the low charge tail in layer 1: dynamic inefficiency? Higher thresholds? Spread of pulse height calibration? → ok. Noted.

- Figure 53: we have to explain/remind what "new modules" means → ok, added to caption.

- Figure 53 and 54: "Avg Norm" has to be explained (or a different term used) → ok. Noted. To be done.

- Figure 56: too much (and too small) text. Move the comment about the temperature uncertainty in the caption → ok. Noted. To be done.

- In figure 58 left (that I suggest to keep and move at the end of section 6.4) a few elements should be indicated with an arrow and a legend and among them the module cable footprints in order to get rid of the sentence presently in line 1623-1624 → sentence has been removed.

Style comments (last update on April 23rd)

- Never use “phase-0”, neither in the text nor in the plots (figure 1). Use, as done in many places in the paper, “original pixel detector”, “previous pixel detector”, … → ok

- “Phase-1” can be used only together with the word “upgrade” or in the expression “Phase-1 pixel detector” once this expression has been defined at the beginning of the paper. For example, the title should be “The CMS Phase-1 Pixel Detector UPGRADE” → ok

- In the paper present and past tense verbs are not used consistently → improved and will also be checked again by LE

- Avoid as much as possible the use of the word “services” and use the correct combination of words: cooling, power cables, optical fibers, … There is almost no need to use generic “services” →ok

- Use the hyphen only when the word compound is used as an adjective. For example “double column” has to be written WITHOUT the hyphen when “column” is a noun. Instead “double-column inefficiency” has to be written with the hyphen. (double column, time walk, base strips, …) → improved, but will also be check again by LE.

- The word “pixel” is used for too many different purposes. First of all it has to be made clear when we refer to the pixel in the sensor and when we refer to the individual channels in the ROCs: presently “pixel” is used in both cases and it could be misleading. In other cases “pixel” is used as “adjective” at the place of “pixel detector” as adjective. This is a CMS jargon but cannot be used in the paper. (lines 454, 519, 526, 1206, → ok, but kept l454 as this refers to single pixel.

- Is the verb “to unify” (and unified, unification, …) the correct one to be used when the trimming of the thresholds? What about “to equalize”? To be checked with someone whose mother tongue is English. → changed to equalize

- For BPIX both the terms supply tubes and service cylinders are used: please use only one of the two for clarity. → ok, should be service cylinder everywhere.

- Use “DCDC” or “DC-DC” consistently in the paper → ok, should be DC-DC everywhere

- I think that “rips” has to be replaced with “ribs” → yes.

- In FPIX the word “ring” is used to define two different parts of the detector: the subset of modules at the same radius in a disk (line 53, Table 1, Figure 31) and the carbon fiber structures where the blades are connected to (and that host the cooling pipes) (lines 904, 966, Figure 31 features both cases!!) . My suggestion is to use “ring” for the latter and use

something different (sub-disk?) for the former. → kept ring for the former, but improved discussion of mechanics.