

General comments (to be checked at every iteration)

- “Bare-module” with hyphen only when adjective (“bare-module test”) otherwise without hyphen “bare modules were built”
- Ask to the pubcomm what is the correct way to deal with the plural form of the acronym and use it consistently. Presently we have “TOSAs” but also “FED” (without “s”).
- Fix any appearance of “pixel” as a short cut for “pixel detector” as adjective. For example in rows 362, 375, 938,
- A uniform approach has to be taken about how the bias voltage sign is quoted: with or without negative sign. Look, for example, at line 587. I suggest to ignore the negative sign not to have problems with statement like “increasing up to -300V”
- Use half-disk (made of two half-rings) and half-ring (inner or outer) consistently in the paper. For example in section 9.2 it is possible that half-disk is used at the place of half-ring several times.
- In several places “optical links” is used at the place of POHs (lines 616, 750, 755, 794). My understanding of the term “optical link” is that it refers also to the fibers and in general to everything which link the back-end boards to the detector (and in particular to the POHs). Can you verify with an English mother tongue colleague and, eventually, decide if it can be used or if it has to be replaced with something like “electrical-to-optical converters” or something better.
- In a few places (for example lines 631, 636, 789, 790, 792-793,...) the term “readout electronics” is used to indicate all the electronics on the service cylinders but not all of it is for the readout of the detector, for example the DC-DC converter or the boards for the power and HV distribution. Can you use a more generic term?
- The message on whether the existing optical fibers have been reused has to be clarified. I think that the ambiguity is due to the fact that the amount of fibers between the back-end electronics and PP1 has not changed but the amount of fibers between PP1 and PP0 (and inside the detector has been increased). This affects statements in lines 782 and 783 (in one line we write that the existing fibers are used and one line after that new fibers have been laid: this has to be clarified), line 267 (where we say again that we reuse the same optical fibers: is it between BE electronics and PP1? To be clarified), lines 1266-1268 (where it starts to be a bit clearer that the additional fibers are between PP1 and PP0 but it is too late in the paper: the increase of the number of fibers have been already described in lines 782-788. Maybe the whole paragraph of lines 782-788 can be removed since the messages it contains can be redistributed as suggested already (see comments below about lines 784-786 and 786-788). In addition, the statements in lines 266-267 give the impression that for some module types we have REDUCED the number of fibers per module, by increasing the bandwidth, in order to accommodate MORE modules using the same number of fibers. Instead this is not true. What we did with the digital readout is to compensate the increase of the hit rate with more performant links and, therefore, we did not have to increase too much the number of fibers per module and we manage to reuse all the fibers between service cavern and PP1 and add some between PP1 and PP0.
- Check that the operating cooling plant temperature is consistent everywhere in the paper: I think that the detector was operated at -22 C, eventually, but in the papers we sometimes quote -23 C (lines 1045) or -20 C (line 1325)
- Check that the number of modules is correct everywhere in the paper. For example lines 1233 and 1234 should be fixed (672 and not 768 FPIX modules) and table 1 should have all the figures about FPIX modules multiplied by four because those are the number of

modules for one FPIX quadrant while for BPIX the number of modules of the whole detector are quoted.

- Every time hit efficiency of single pixel efficiency or something similar is referred to we have to make clear that there is no ambiguity and we have to provide sensible definitions (even if not with all the details) for all of them. These concepts and the results of the measurements appear in several places (I don't know if the list below is complete: to be checked):
  - "data loss" in table 3: does it refer to the hit (cluster) loss or to the single pixel (within a cluster loss)? I guess the former.
  - Figure 6: "Efficiency" in the vertical axis. The efficiency measurement with the X-ray is introduced for the first time here and later referred to in lines 535-542. It is based on the PixelAlive test (line 540) and therefore on detecting signals injected in single pixel but this is not known at the time of figure 6
  - Line 324-325: here we refer to a "hit efficiency" which is above 95% while in table 3 we claim that the data losses have to be less than 2%. If the inconsistency is due only to a different definition (cluster efficiency vs single pixel efficiency) it is better if it is clarified.
  - Figure 7: Here it is called "single pixel hit efficiency" and it should be the same of figure 6 and lines 535-542 (PixelAlive). The caption of figure 7 should indicate "Pixel HIT rate"
  - Figure 13, its caption, and text that refers to it (line 540). Here it is called "hit efficienCY" (there is a typo in the caption of figure 13) but I think it is like figure 7: single pixel hit efficiency. Can you fix it if confirmed? Incidentally it is not clear if what is shown in figure 13 is the average efficiency in a ROC, in a double column (look at the text which refers to this figure and the discussion about DC efficiency measurement and DC uniformity) or in a single pixel.
  - Line 566: "efficiency" should be clarified: "single pixel hit efficiency"?
  - Line 1555 and figure 49 top left: Which kind of efficiency is described here? It is called "hit efficiency" but it is not the same hit efficiency described before. Here the hit/cluster is considered good also if he has lost some individual pixels.
  - The whole section 11.4.4 should be consistent with the definitions of (single pixel) hit efficiency and (cluster) hit efficiency discussed above
- Do we want to call the 40 MHz communication protocol as "modified I2C interface"? (for example, line 242 or line 753). I remember Wolfram commenting that the comparison is not very meaning full. We could refer to it as a "40 MHz 2-line communication protocol". Agree with the experts.
- Around line 556 clarify that this value of  $V_{cal}/ele$  conversion factor is valid for PSI46dig, explain that this is the value used consistently in the rest of the paper (is that true? ) (and remove the statement from the caption of figure 12) . Report the results about the dependence of this conversion factor on the irradiation and whether this dependence is taken into account, for example, in the threshold trend plot (fig 44). All this should replace the statement of lines 1560-1562: at that moment in the paper it has to be clear that  $V_{cal}$  depend on radiation. Incidentally the statement of line 1560-1562 seems to indicate that we did NOT consider the evolution of the  $V_{cal}/ele$  factor when the gain calibration was applied to the data while I am not sure that this is the case. The results of figure 49 could be affected also by the fact that the gain calibration was, simply, not done frequently enough. Also the statements in lines 1437-1439 should take into account that the  $V_{cal}/ele$  conversion factor has been already described in section 3. In particular, the statement of

lines 1437-1439 should be removed or should make clear that an average value is used and not a value per module (if I am not mistaken).

Statements that should be made earlier in the paper or that are made more than once and, therefore, have to be rephrased.

- Lines 357-360. The sentence about the automatic reset is repeated twice. One of them has to be removed. In addition I would modify it in the following way: “ The FUNCTIONALITY of issuing an automatic reset was added ...”. Otherwise it may give the impression that it cannot be disabled.
- Lines 360-364 introduce again the 70 Hz reset signal already described in line 320. Therefore I would rephrase into something like (replacing the sentence starting with “Since the automatic reset”): “However this functionality has not been used and it was decided that the periodic reset signal, used to recover from the loss of synchronization of the PROC600 chips, were issued, centrally, by the CMS Trigger and Control system after 3000 bunch crossing without L1 triggers in order to drain the data from the ROC buffers and avoid to lose them” or something like that .
- Line 409-410. The sentence “The goodness of the ... tests” sounds like a repetition of the sentence before (lines 408-409): “The quality of the bump-bonding ... production center”. Can the latter be removed? Moreover, in line 409, “production center” is a bit jargon. Replace with something like “module assembly center”.
- Line 485. I think that the standalone sentence “A calibration ... preamplifier” can be removed because the presence of a calibration signal functionality was described already before (line 246). Maybe the description in line 246 can be enriched with “at the input of the pre-amplifier”.
- The two sentences in lines 653-657 look oddly placed. The information about the power to be dissipated should not be added in the middle of the description of the cooling loop layout and assembly, possibly at the beginning (around line 640). The sentence about the cooling loop length should look like a conclusion of the whole description. Something like “The RESULTING cooling loops have a length...”. The sentence about the VCR connectors does not require a dedicated paragraph and can be added to the previous paragraph (lines 640-652).
- If I am not mistaken the 6-ply carbon fiber skin introduced in line 687 is the same as the one of line 692. If this is the case at the least the word “the” should be added before “carbon fiber skins” to make clear that they are the same as the one referred in line 687.
- Line 701: The fact that TC5022 is used is already said in lines 688 and 691. My suggestion is to remove the sentence “In both cases ... gaps” and, maybe, add in line 702 something like “... to the assembly procedure, including how TC5022 is applied, proved necessary...”
- Line 776: the aluminum flex cable of FPIX were already introduced in line 740. If we introduce the micro-twisted pair copper cable of BPIX around line 623, then we can move the sentence of line 776-777 (or replace it with something like: The 400 Mb/s data stream... are transmitted electrically to the POH along the module cables”.
- The information equivalent to the statement in lines 786-788 about the bandwidth increase going from 40 MHz analog to 400/320 MHz digital has to be moved in the paragraph of lines 337-348 and removed from here.
- The information in lines 784-786 is already in table 4 and at the beginning of section 3.4 and 3.5. Maybe lines 784-786 could be replaced by the information about the number of fibers for BPIX L3-L4 and FPIX modules (one per module = xxx) for BPIX L2 modules (2xnumber of modules) and for BPIX L1 modules (4xnumber of modules).

- line 790. The reference to power and cooling should be removed from here OR this comment about the different design between FPIX and BPIX should be made in the mechanics section (4) explaining that these differences will be described in section 5 for the electronics and in section 6 for the DCDC converters (the differences about the cooling pipes are already in section 4)
- Lines 792-795 should refer to the segment names (A,B,C,...) already introduced in section 4 to make clear that we are talking about the same thing. The DC-DC converters, if possible, should be ignored or referred to as a side remark since they do not belong to the DAQ system. The segment names should be used also in lines 801 and 803-804 when the connector boards and the POH mother boards are referred to.
- The statement of lines 795-797 should be removed or rephrased because it is not something new: it was stated in line 641.
- The statement of line 813-814 does not belong to this section. It can be moved in the mechanics section where we can write that the detail of the arrangement of the electronics on the service cylinders is described in section and the distribution of the LV and HV power lines in the BPIX and FPIX detectors are discussed in section 6.
- Line 892: as for the DAQ section, remind here the service cylinder segment name with the DC-DC converters
- Line 893-896 should be rephrased to take into account that in line 890 “an extension PCB” is already introduced is it the “extension board”?
- Lines 1100-1101 contains a sentence which is repeated immediately after.
- Lines 1127-1128: the sentence about the modules mounted both inside and outside the mechanics should be removed because this has been said already in lines 599-600
- Lines 1145-1147 contain details already described in lines 893 where, on the other hand the role of the thermal bridges is not written explicitly (even if it is pretty evident). My suggestion is to introduce the cooling bridges already in section 4.1 as the elements which keeps the cooling pipe in place and ensure thermal contact with the components that will be mounted on them. This will allow to refer to them in line 893 and in line 1145-1147, without the detail about the thermal contact.
- Line 1172-1174: both the mini-fitting and the connector boards have been described previously in the paper and, therefore this sentence can be removed. If felt needed details can be added in line 1166 by specifying that the detector and the service cylinder assembling consists (also) in connecting the mini fittings and the connector boards to the service cylinder. But we can also not do that.
- Line 1216-1217. The description of the filter boards and of their pigtailed have to be moved close to line 902 and in lines 1216-1217 only the integration sequence have to be described.
- Line 1349: The sentence “Each POH is equipped with 4 or 7 lasers” contains an already described fact. It should be rewritten into something like: “The 4 or 7 lasers of each POH can have their bias current and gain adjusted independently”
- Line 1351-1352: maybe this piece of information should be in section 5.
- Line 1378: the sentence about the threshold having to be the lowest as possible is a repetition of what is said a few lines above. In my opinion it can be removed.
- The description of the calibration of CalDel in lines 1385-1388 is a repetition of something said in line 486. Here we could simply say that CalDel is determined as described before. If some parts of the sentences here are still useful, they can be added to line 486, instead, to make the description complete there.

- At the end of line 1491 add a statement like this: both at the beginning 2017 and 2018 pp collision physics run, an alignment whose quality was good enough for the HLT track reconstruction have been achieved withing a few (quantify how many) weeks together with the parameters needed for the reconstruction of the hit position (LA and cluster shape parameter) [reference-to-tracking paper]. In this way the references to LA and templates in the sentence in lines 1492-1494 can be removed.
- Line 1520-1521. The motivation to do the GainCalibration should be moved in section 10 where the calibration is described.
- Lines 1573-1574: the fact that radiation change the sensor response has been said already, no need to repeat. Instead we could write something like: “Based on the results of HV bias scans whose fig 49 and 50 are an example, the HV bias setting has been adjusted periodically as described in table 5.”
- Lines 1586-1590: the fact that with n-in-n sensor it is possible to operate the sensors also under-depleted, should be moved to the section about the sensors where the n-in-n technology is described, around line 182.
- Lines 1613-1620: the numerical argument about why a large LA value is good and allow for achieving a good charge sharing with a 100x150 um pixel should be moved in section 3.1. (and complemented with the information that the large LA is competing with the wish of having a large signal and, therefore, of increasing the bias voltage, especially after irradiation). Here in section 11.4.3 (or wherever we move the LA results) we should ONLY remind (with references) the methods used to measure the LA and show the trend plot highlighting the correlation with the HV bias setting changes.
- The statement in lines 1641-1643 should be moved somewhere in section 3.2 because it is there where the dynamic inefficiency is described for the first time (for example figure 6). Here, in section 11.4.4 we can simply remind that we measure the dynamic inefficiency (introduced in section 3.2) and the effect of the synchronization loss in the PROC600 chip.
- The statement in line 1655 about the dynamic inefficiency of the original detector could be irrelevant because the original pixel detector had also bandwidth limitation that would have made running at  $2 \cdot 10^{34}$  (and 100 kHz L1 rate) impossible. Such a statement should be made (more or less quantitatively) in the introduction to motivate the upgrade of the pixel detector and in line 1655, if you like, you can quote that a similar inefficiency has the one observed in the Phase-1 layer 1 was observed at much smaller luminosities in the original detector.

#### Other style and clarity related comments

- Paper title: “The Phase-1 CMS Pixel Detector Upgrade” : swap CMS and Phase-1
- Rephrase lines 44-45 since “The CMS silicon pixel detector” is not well defined since there is an old and a new detector. Something like “CMS has adopted strategy of having a silicon pixel detector as its innermost tracking device”.
- Lines 54-56: add somewhere something like “In order to maintain efficient ... .. until the end of Run 3 (2023)”. In this way it is more clear why we are naming this upgrade “phase-1”.
- Line 56: replace “pixel detector Phase-1 upgrade” with “Phase-1 pixel detector” . In this way we define this term.
- Line 60 (see also comment about lines 54-56). Complete this sentence with something like: “...after which the whole CMS Tracker detector is expected to be replaced completely in view of High Luminosity LHC (phase-2 upgrade) [reference to the TDR]”
- Line 71: section 8 is not referred to.

- Line 75: “cylindrical barrel” is an excessive repetition: the central part of the detectors is called “barrel” because it has a cylindrical shape, like a barrel. We can remove “barrel” and leave “cylindrical layers (also referred to as barrel)”
- Line 94: “allowed to install” to be changed into “allowed for installing”
- Table 1: the concept of ladder is not defined yet. At the same time the number of ladders is not even in the table. Either ladders are briefly introduced around line 84 and the number of ladders is added in table 1 (even if it is just the number of modules divided by 8) or “ladders” is removed from the caption.
- Table 1: the way the barrel z position is reported is not very nice: the tiny difference between the minus sign and the dash is confusing. At least you can add the “plus” sign to make clearer the message.
- Line 101: replace “current” with “original” (this has to be checked everywhere in the paper)
- Line 102: add “PARTLY reuse” and remove the text in parenthesis: the fact that the power cables are reused is explained in line 108, the fact that the optical fiber BETWEEN THE BACK END ELECTRONICS AND PP1 are reused is in line 105 and it is NOT true that the cooling lines have been reused: new cooling lines have been deployed.
- Line 123: no problem if you want to quote 500 fb-1 as a benchmark for the hadron fluence. On the other hand it is not the projected Run2+Run3 luminosity. As of now it is ~370-400 fb-1. If you want you can, therefore, use 400 fb-1 or remove the statement “as projected for ...”
- Line 128: you should comment also about the increased reate in the other layers to justify the new PSI46dig. Something like “The ability .. ... almost 600 MHz/cm<sup>2</sup> in BPIX layer 1 and 2-3 times more than in the original detector in the other layers and disks”
- Line 134-135: already here it has to be said that the sensors are segmented in rectangular “pixels” in order to be able to talk about “pixels” already in line 137.
- Line 136: strictly speaking the acronym “ROC” is already defined in line 86. Maybe you can remove the definition there.
- Table 2: the column with the value of the radii is already in table 1. I think it can be removed from this table.
- Table 2: I think there is no need to quote the fluence and the dose both for 300 and 500 fb-1. Maybe only 400 or 500 is enough. An exception could be done for L1 by quoting (only) 300 fb-1 (since it will be replaced in LS2).
- Line 146: it is not clear the meaning of “central region”. Do you mean “barrel” or “eta~0”? In both cases I would be more explicit by reminding that the Lorentz drift play a role (see comment about lines 1613-1620) as well as the main feature of the resolution along z.
- Line 150: can “inner assembly” be replaced by “inner ring”? I am not sure we are referring to them but if this is the case I would use the same nomenclature.
- Line 151: is “interaction point” the correct term or is it “beam axis”? Or is it “with respect to a straight line from the interaction point” ?
- Line 151: I would refer also to figure 1 and not only to figure 20.
- Line 151: replace “pixel orientation” with “sensor orientation”
- Line 154: add that the z-axis is orthogonal to the sensor plane
- Line 162: I don’t think that “their proposed lifetime” is correct. In the TDR the proposed lifetime was 250 fb-1 while in Run 2 the integrated luminosity is much less. I would replace with the actual integrated luminosity in Run 2: the sentence will continue to make sense.

- Line 176: add a reference to a paper which compares/measures electron and hole mobilities?
- Line 177: add a reference about radiation damage that reduce charge collection? RD48/RD50 papers?
- Lines 176-177. The motivation of the sentence “The charge collection ... .. charge signal” is not clear.
- Line 178: The use of “Another advantage” sounds strange because in the previous sentence the fact that the high mobility is an advantage is not clear. See comment about lines 176-177
- Lines 182-184. Modify accordingly to the comments about lines 1613-620 and line 146. The fact that large mobility leads to large Lorentz angle which leads to charge sharing is scattered across the paper. Make clear that, at least, it refers to what was said before.
- Line 192: is there any reference to quote about the need of n-side insulation? A paper where this effect is described in details once for all?
- Lines 196-212 and 216-224. You should check if this detailed description of the n-side insulations in BPIX and FPIX was already in the original CMS paper and, if this is the case, it should be shortened and a reference to that paper should be made. To my knowledge these details are identical to the original detector sensors and there is no need to describe them again if already described in details in the past.
- Line 215: you should quote the temperature at which this measurement is done
- In section 3.2 it has be said which is the voltage needed to operate the ROCs and the fact that there are regulators. This will affect what is written in line 848 because it will not be the first time anymore.
- Line 239. It is not clear to me what “They” refers to.
- Line 241. “ROC” should be replaced by the name of the ROC type.
- Line 260: the statement “the data acquisition is stopped” is not very clear because there is no reference to an “ongoing data acquisition” before. Can you clarify what has to be stopped?
- Line 261. The word “discarded” gives (me) the impression that if the matching L1A arrives later, the data are already lost. Does it work that way?
- Line 266. I don’t think that the word “module” is needed. I think that “adoption of 160 Mb/s digital readout” is ok. Same comment also for line 754.
- Line 305: I think that the higher noise in PROC600 and, therefore, the higher threshold, is addressed in Section 10, too.
- Figure 7 and text that refers to it. My suggestion to address the ambiguity of the reset during the test (one reset every event), the reset during data taking (at 70 Hz, line 320) and why we did not realize before the installation that there was a problem in PROC600 V2 is the following:
  - We do not mention the fact that the PROC600 V2 results WITHOUT the reset were not widely available before the installation. The reader will understand by him/herself that something went wrong in the communication chain.
  - In line 324 we comment that the results shown with the orange lines (V2 with resets) show the effect of a reset every event and when, instead, the reset is issued only at 70 Hz frequency only the low luminosity inefficiency is cured completely while the high rate inefficiency is not partly recovered (and we refer to section 11). An even more ideal solution would be performing a test with the X-ray machine where a 70 Hz reset is issued and the efficiency is measured as a function of the

pixel hit rate. Would it be possible to do it? All above will require a reshuffling of the statements in lines 319-324 to have them in the correct order.

- Line 331. Replace “L1 trigger signal” with “L1A” since we used that term before. Explain that it comes from the CMS back-end trigger electronics. (reference to L1 trigger CMS paper?)
- Lines 344-348. I am not a TBM experts but I am confused by the statement that one 160 Mb/s path is kept in sync with the other one by adding zeros only in TBM09 and TBM10 and not in TBM08. I am also confused by the TBM08 paths being INdependent while the ones of TBM09 TBM10 are more dependent. I would have guessed the opposite.
- Line 364. Add that “Delay adjustments were added” because of the novel digital readout.
- Line 380. Replace “rate of modules” with “rate of TBM cores” (which is a quarter of a module).
- Line 386. VERY likely we are not going to replace FPIX modules with new modules with new TBM08. I would then remove “serviced” if you agree.
- Line 423. Replace “long module cable” with “long final cable”
- Line 451. Indicates how many sites were involved
- Line 457. Move “software controlled” after “The gantry is software controlled for...”
- Lines 484-488. Reading these sentences, it is not clear what are the two parameters which are adjusted: CalDel and Vthrcomp or CalDel and VCal? I think the former in this case.
- Line 521. Replace “for later use” with “for offline reconstruction of the hit position” (I think this is the main application)
- Line 543-546: this part is not very clear to me. It looks like a way to increase the statistical accuracy and measure the efficiency per DC instead of individual pixels, not a big deal. Furthermore, the detail about the uniformity is not explained neither here nor in line 567 where the selection criteria are listed. From what is written in line 566-567 I would conclude that the uniformity cut is tighter than 2% being 98% the absolute efficiency cut.
- Figure 14 caption. Replace “characteristic X-rays” with “monochromatic X-rays”?
- Figure 14 caption:  $47 e^- / Vcal$  is not what is in the stat box of the figure. I guess this is because 47 is the average of all the modules. Since the average factor is already in line 556 I would remove it from the caption of figure 14.
- Line 574: the statement “that is not related to the assembly” leveas the reader with more questions than answers. What is the message we want to convey? Let’s indicate positively what we think are the causes.
- Line 583. Add “THE damage that occurred” since it has been described before.
- Line 587. I think that “radiation damage” should be replaced by “collision-induced radiation” in this case
- Line 587-588. Replace “data-taking” with “pp collisions”: it does not matter if we were collecting data or not.
- Figure 15. I think that what is shown in the plots is not the yield (which should be a relative number). “production trend” should be ok.
- Lines 590-591. In FPIX mechanics there is also grafite, not only carbon fiber. This sentence has to be fixed.
- Add in the introduction of section 4 that the carbon fiber and the grafite contribute also to the cooling since the cooling pipes are not in direct contact with the modules and that the electronics act as pre-heaters for the CO<sub>2</sub> 2-phase cooling. These complete the list of features of the mechanics of the pixel detector

- Line 593. Remind that the service cylinders host the auxiliary (readout and DCDC-converters) electronics, to make the introduction complete.
- Line 598. Make clear that the quoted overlap is among the active sensors (I guess)
- Caption of figure 16. Replace “facet” with “ladder” since this is what we have used in the rest of the paper
- Somewhere between lines 614 and 626 it has to be made clear that eventually BPIX is made of two parts each one composed by one service half cylinder, half detector and another half service cylinder: as of now the overall composition is not very clear.
- Line 678. Remind that the half-disks are the basic unit of the FPIX detector. They were introduced in section 2. Maybe even just swapping the sentence which starts in line 680, “The three half-disks ... “ with the sentence which starts in line 678. “The FPIX half-disks...” would help.
- Either you start a new paragraph in line 708, after “The skins are ...” , or you do not start a new paragraph in line 716.
- Line 725. Reading the description about the support feet I have the impression that they are present only on the detector end at large absolute z while, I think, there are feet also at z=0. Can you clarify the text if this is the case?
- Lines 727-732. This paragraph is about the corrugated part and has to be moved before line 722
- Line 734. When “thin walled” is written, add also the numerical value of the pipe wall thickness. I think it is 130 and 200 um depending on which pipes
- Line 749. Replace “DAQ modules” with “DAQ backend electronics boards” or whatever is used in the pixel DAQ paper
- Line 753: make clear that “communication” does not mean “data transfer”. It is for control, programming and readback.
- Line 754. I think that “digital readout datastream” is better than “digital module data”
- Line 770. In the pixel DAQ paper we called the “FEC” “TkFEC”. Can we use the same name?
- Line 778. What is the correct term? Laser TOSAs, TOSA lasers or just TOSAs?
- Line 805: add that the fibers run to the end flange
- Line 845: more specific on the input voltage used during operations
- Line 846. Find a way to make clear we are talking about the supply lines between the DCDC converters and the modules: “downstream supply lineS”?
- Line 849. I think that in the introduction we should remind that there is also a power distribution for the auxiliary electronics and the HV distribution. Both conceptually similar to the ones of the original detector.
- Line 858. Negative resistance could be misleading: I think you mean that dynamically it is like a negative resistance ( $\Delta V$  and  $\Delta I$  have opposite sign, not  $V$  and  $I$ )
- Either something about HV is added, otherwise 6.2 should be renamed “LV power distribution” in my opinion.
- Line 898. I would specify that the pair of DC-DC converters is one for the digital power and one for the corresponding analog power
- Line 902. Clarify which “end” of the service cylinder
- Line 905. I think that we have not always multiplied by four with other parts were counted. I think that the statement in parenthesis can be removed
- Line 909. If it is one FPIX CCU board per half cylinder I would write: “In each FPIX half cylinder one FPIX CCU boards, each carrying four CCUs, is used...” to remove any ambiguity
- Line 910, add also “and one power good bit line”

- Line 916. Are we sure that “multi-service cable” is not jargon?
- Line 939. Start a new paragraph with the sentence “The electronics components...”
- Line 957. Do not use “now”. It will be inaccurate by the time the paper is published.
- Line 957. “a certain transistor” sounds odd to me. Do we really need “certain”?
- Line 958. I think that “which is” can be removed: “...leakage current amplified...”
- Line 961. Add at the end of the paragraph something like “...damaging and making them unusable”
- Line 970. The word “cooling” appears too many times
- Line 974. “thermodynamic performance” is too generic (and odd). Select two/three features and list them.
- Line 987. The sentence in parenthesis is pretty obscure. I think it refers to the fact we have defined a couple of nominal operating temperatures “low temperature” and “room temperature” but this is not known to the readers and ends up to be difficult to understand. Rewrite.
- Line 988. The extracted heat is also the one produced by the leakage current of the irradiated sensors, unless line 988 refers only to the pre-heating. In this case make it clearer by adding something like “before reaching the sensor modules”.
- Figure 28 caption. “upper” and “bottom” are swapped.
- Line 1012. Add also in the body of the paper the values of the pressure the system is expected to operate at (20-50?) and that it is tested at up to 157 bar.
- Line 1017. The fact that each cooling plant “owns” one subdetector is not known. Either it is explained before or replace “its own” with “one”.
- Figure 30 and 28 look pretty similar: it would be better if they were unified. In particular figure 30 is more CMS-oriented but figure 28 has a few additional details that could be worth adding to 28. Having both is a waste of space.
- Somewhere in section 7.3: we are missing the description of the vacuum jacketed transfer lines and how the vacuum behaves and is ensured.
- Somewhere in section 7.3: add the values of the nominal CO<sub>2</sub> flow and refers to section 7.5 for what concern the adjustment done in 2018.
- Line 1057. What is the message we want to convey with “stand alone”? With respect to what?
- Line 1066. Clarify that reducing the flow reduces the “absolute temperature” in the detector region.
- Figure 32. Can we have also the lines in the right plot solid and not dashed? The fact that the azimuthal angle is a measurement of the position along the cooling loop is not so obvious. If it were converted in ladder number of length along the cooling pipe would be clearer. Otherwise this has to be explained better in the text (referring to the geometry of the cooling loops described in section 4)
- Line 1078. Also the testing of the (novel) power system was one of the goal of the pilot system
- Line 1082. Too many “system”. Rephrase
- Line 1083. It is not correct: the FED f/w was developed during the pp collisions, not during the test stand operations. This has to be made clear also in lines 1091-1092.
- Line 1100. Add that also the noise in the Strip tracker was checked and no effect was observed
- Line 1114. Is “in the center” correct? What about “in the middle”? “Center” sounds like a point to me.

- Line 1133. “half of the BPIX detector” may sound misleading, as if only half of the detector was assembled. Rephrase
- Line 1176. We have not specified the name of the Lucasz plant. No need to mention CO2LEAN name (also because there is no reference).
- Line 1199. Maybe we should add “fully assembled AT FNAL”
- Line 1222. “modules” is too generic. Add “sensor modules”.
- Line 1222. Are those cooling structures with DCDC converters the DCDC converter mother boards already introduced in section 6 and a few lines above? If so, call them in that way, if not, I am confused.
- Line 1229-1230. I think it is a detail that it is not relevant for the paper. I guess we had a few others changes in the original design and procedures that we have not described in the paper.
- Lines 1243-1246. It is not easy to understand what is wrong with this procedure. If we really want to describe this detail, it has to be made clearer. Is it relevant that in line 1243 “CO2 gas” is referred to and in line 1245 “CO2 liquid”?
- line 1255. What constrains the pixel volume is not the first layer of the strip tracker, it is the pixel support tube which separates the pixel from the strip tracker volume.
- Line 1256. The rails are on top and bottom of the pixel support tube inside CMS.
- Line 1259. The endcaps are those of the muon and calorimeter detectors of CMS
- Line 1264. PPO are at BOTH ends of the pixel detector, on the Strip Tracker bulkhead, both sides.
- Line 1273-1276. I would rephrase to make it sound less a narration of a story. Something like: “to verify the installation tools and procedures, the installation was rehearsed using a mockup of...”. I would skip the comment about the fact that the test installation went smoothly, otherwise we should describe all the other test installations done in the previous years and explain what we learned from them.
- Line 1280. Have we defined what “-z” means? If not and if we do not want to do so, I would remove this detail.
- Line 1294. It is not clear what “increase” refers to. I would remove it. We did not have capillaries in the original detector and therefore there was not a less complex configuration that allowed a different installation sequence.
- Line 1296. “final installation” sounds misleading to me. What about something like “prior to installation completion” or “prior to sliding completion” or “before the half cylinder reached their final position”?
- Line 1297. We have already described the simultaneous installation in lines 1292-1294. Maybe we can move it from 1292-1294 and move it here. Something like “...was monitored. This allows modules in the two different half cylinders to overlap...”
- Line 1300. Explain to what the capillaries were connected. PPO?
- Line 1313. Replace “nuclear interactions” with something like “the reconstructed vertices of the NI of hadrons from pp collisions with the detector material”.
- Line 1326. Is “was taking” correct?
- Line 1331. Is “unification” correct? I would use “equalization”
- In section 10, remind that the calibration procedures are similar to the ones of the original detector (add reference [2] here) with the exception of the tuning of the phases novel digital readout. This would add a bit of content to the introduction.
- Section 10.1 is pretty unclear to me: 1) it is not clear if the first and second paragraphs refer to the same lines and the same parameters, 2) it is not clear why the comment about

the (hardware) delays is relevant in this section if the calibration is only relative to the programming lines (there is no need to have them in sync among the different modules, while this is relevant for clock and trigger distribution which are not mentioned in this section), 3) Only in the second paragraph it is mentioned w.r.t. the phase is adjusted (data vs clock) while in the first paragraph it is very vague (it is about clock and ??). The list of what is synchronized with respect to what has to be made clearer.

- Line 1356. Replace “channel” with “optical link” or “fiber”. Same comment also for the caption of figure 42
- Line 1358. Is it really a “readout group” or is it a FED?
- Figure 42: If I have understood the text and the plot, would it be possible to draw 12 or 24 lines instead of one set of point (the average values?) and the spread? The individual lines make more sense because each one of those lines is used to set the bias of each laser INDIVIDUALLY. If the plot become too crowded, restrict to only 12 lines (or even 6 for illustration) but let’s not pass the message that the set point is extracted for a plot like the present one in figure 42. Drawing a horizontal line at 0.1 mA would be useful, too.
- Section 10.3. Comment that this is new w.r.t. to the original detector
- Why section 10.4 title contains “charge injection”? Is it a tool but it is not something to be tuned or calibrated. In addition the title should say: “threshold TUNING and noise measurement”.
- Line 1381. The expression “relatively non-uniform threshold distribution” is not clear: does it refer to among different ROCs or within a ROC? And it is not clear if anything is done to improve it (and if it has to be improved in the first place) because it is not clear if the trim bits are adjusted. Somewhere close to this line we should also say that for BPIX layer 1 we did not try to choose the lowest possible thresholds because we knew that with higher rate the noise would be higher and, therefore, we decided to start with more conservative values. This is partly described in lines 1398-1399 but it is too late.
- Line 1382. What does the “calibration of the analog pixel response” refer to? Pulse height calibration? Threshold equalization? It has to be clarified.
- Line 1384. Why are the trim bits referred to here where the analog pixel response is described (not very clearly...)?
- Line 1400. Actually Hans-Christian explained that the largest contribution to the timewalk effect comes from the discriminator more than from the amplifier. Discuss with him a proper expression.
- Line 1405. No need for a new paragraph.
- Line 1046. Is there no impact on the time walk of BPIX layer 2 by the sub-optimal time alignment?
- Lines 1415-1416. I would not start with “In 2018” because it gives the impression that eventually we run with lower thresholds during 2018 run.
- Line 1418. Add also that the new PROC600 will feature a lower cross talk noise.
- Line 1426. Why “conversionS” plural?
- Line 1426. Shouldn’t it be “FROM units of ADC ...”?
- Line 1431-1434. The sentence, as it is written, does not make clear that not only the Gain calibration results depends on the PHOff and PHScale setting, but, also, the optimal PHOff and PHScale setting have been tuned, at least once per year, thanks to the results of the Gain calibration.
- In line 1462-1463 the fraction of affected modules should be added. 1-2%

- Change the title of section 11.2 into something like Detector time and space alignment with first collisions
- Line 1485. The word “alignment” is a bit jargon. Something like “For a proper reconstruction of the charged particle trajectories (or tracks) and their momentum measurement with the at the time just installed detector, the actual position of the sensors has to be known with an accuracy of ~10 um or better. The procedure to determine these parameters, known as "alignment" relies on the signal released by the pp collisions and the cosmic ray muons and is described in Ref [57].”
- Line 1488. Replace the sentence that starts with “The alignment reached...” with something like “...reaching a statistical accuracy of the module positions of a few microns [58]”
- Line 1496-1497. Is there a reference for these measurements? Can [13] be used?
- Line 1500. Clarify that the readout is interrupted only for the affected channels.
- Line 1505. We should quantify how often the recovery procedures have been triggered and explains that they are triggered only when the number of affected channels reach a programmable threshold (no need to go in details with the threshold descriptions if we quote the rates of affected channels and the rate of recovery actions).
- Line 1506. Start the sentence with “In addition, in order to recover...”
- Line 1506. Add “...affected by SEUs in the TBM(s?) THAT CANNOT BE RESET...”
- Line 1508. Explain briefly that the procedure is started when a programmable threshold is passed.
- Line 1521-1522. Add that monitoring the collected charge is also a way to monitor the effect of the radiation and other sources that affect the charge collection and that can endanger the hit efficiency.
- Line 1531-1532. No need to introduce the concept that the radiation can affect the charge collection so late. Move it close to lines 1521-1522 (see comment above)
- Line 1529: “not for all” is not needed if the message that radiation can reduce the charge collection is described earlier.
- Line 1533 and figure 47. Something has to be added about the shape of the layer 1 distribution and the fact that it could be affected by the higher threshold and the by the data losses due to the higher rate. This partly described in the caption of figure 47 but it should be moved in the body of the paper.
- Line 1534 “pixel charge” is jargon.
- Line 1535-1537 that describe the method should be moved a bit earlier and integrated in the sentences of the previous lines.
- Line 1538. There is not the curve of an unirradiated sensor in figure 47. The sentence seems to indicate the opposite. It should be rephrased. For example by starting to describe the results of the irradiated sensors and commenting that they deviates from an ideal flat response.
- Line 1543-1544. I would conclude this sentence with something like “...partly recovered by a proper modelling of the radiation effects in the offline reconstruction.”
- Section 11.4.2 . In the title “sensor bias” should be replaced with “sensor depletion voltage” or “sensor response to HV bias”
- Line 1548. Another reason that allow for different HV setting is that for FPIX a large LA value is not important and we can focus on an efficient charge collection without the need of too many adjustments during the data taking. If it is not said before this is the right moment to explain it. This is partly said in the following lines (1550-1554) but it has to be

made clear that it affects only BPIX and, therefore, for FPIX we can start with a higher bias value without too many problems.

- Line 1555. Add that we show L1 because it is the most affected by the radiation.
- Line 1566. I think that “where” should be replaced by “and”
- Line 1567. Add “the cluster size IN THE DIRECTION OF THE LORENTZ DRIFT”
- Line 1570. Before discussing L2 results we should comment on the comparison between old and new Layer 1 modules and on the fact that from these plots the effect of the beneficial annealing is visible in the old modules.
- Lines 1570-1572. It has to be reminded that in L2 the radiation is about a factor 4 less than in layer 1. Figure 50 should show only the curves that correspond to the SAME scans used for the L1 plots. In addition, in figure 50 it is not clear how the luminosity is computed. If 0 luminosity is the beginning of 2018, then it has to be modified to consider the 2017 luminosity as it is done in the L1 plots. In general, the integrated luminosity values should be quoted in a consistent way in the paper.
- Caption of figure 49: Add “BPIX L1”, replace “angle” with “drift”, replace “z direction” with “in the direction parallel to the B-field”
- Table 5. I think that the setting of the FPIX HV in the last point is not ok: inner and outer ring modules should have different values.
- Lines 1575-1590. Given what has been discussed in Helsinki during the monitoring meeting and the fact that people are still working on these results my strong suggestion is to remove this part and figure 51. In any case the message that these sensors can be operated also when not fully depleted is described when the n-in-n sensors are described (section 3.1 following a comment above). We can add a comment, when the results of figures 49 are described that the evolution of the position of the “knees” follows in a quite satisfactory way the Hamburg model both for what concern the effect of the integrated luminosity and the effect of the annealing during the warm periods (and that more detailed results will be presented in future publications).
- Lines 1591-1611. Some comment as above. Remove the model predictions from figure 52: we are not ready to publish with this not yet understood scale factor. Describe that we have measured periodically the leakage current per module, that it evolves proportionally with the integrated luminosity and that it shows the annealing behavior as expected according to the Hamburg model. Conclude that these results confirm that by the end of Run 3 there will be no problem of overcurrent with the existing power supplies. At this point these results can also be moved in section 6 because they do not depend on the pp collision data and the conclusion, for the moment, is only about the power supplies. If you like the four curves can also be combined in a single plot since, without the model predictions, the plots will be pretty light.
- Figure 53: once we have the final plot we have to check if it is consistent with table 5. And the integrated luminosity has to be quoted consistently.
- In section 11.4.5 my suggestion is to ignore the complication of the outermost (and innermost) layers and present it as a sort of preview of the more detailed performance paper. Only the simple case of BPIX L3 is presented.
- Line 1673: replace “extrapolation” with “interpolation”
- Line 1676: clarify if the 5um effect is on RMS or resolution
- Line 1681-1683. In my opinion this sentence can be removed if we present these results as valid only for L3.
- In the summary remind about the refurbishment during LS2
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## References

- Improve references [20] and [21]
- Line 1625. Why reference [63]? Don't we have it described also in [3] or [61] (I have not checked but I would expect so)?
- Line 1633. Reference also to b-tagging paper?
- DOI should be added to all the references when possible

## Typos

- Line 100: SHOWN
- Line 1140: FOUR
- Line 1217: ConnectiOns