

We want to congratulate the authors for putting together this very comprehensive paper. Overall we found the quality of the paper to be very good. While there are many comments below, this primarily reflects the length of the paper rather than a need for significant changes. We enjoyed reviewing this paper, and look forward to seeing it published.

The Cornell CMS group

Note that all comments are based on this version of the paper:

https://twiki.cern.ch/twiki/pub/Sandbox/TrackerPhase1PixelPaper/Phase1PaperDraft_v8.pdf

Grammar, Style, Formatting:

General grammar comments:

- <https://twiki.cern.ch/twiki/bin/viewauth/CMS/Internal/PubGuidelines#Commas> suggests using the Oxford comma, and it seems that the paper currently uses it in some places but not everywhere. It would be good to be consistent. Some example places where it could be added in follow--but this is not a complete list!
 - 50: 73-> 73,
 - 73: 6 -> 6,
 - 74: readout electronics -> readout electronics, → here no comma as “readout and DAQ” is one item in the list
 - 429: Finland -> Finland,
 - 649: 30.4 -> 30.4,
 - 808: clock -> clock,
 - ok, checked the whole document and added Oxford commas
 - The phrase "so-called" is frequently used in the paper, but is unnecessary in many or potentially all cases. Consider dropping them (or in the case of e.g. line 859, replace "the so-called port card" with "known as a port-card"). → ok replaced or removed (in particular when there is a reference)
0. Abstract
- “...after the first long shutdown...” -> “...after the 2013-2014 long shutdown...” or “...after the first long shutdown in 2013-2014..” → ok
 - “...to provide a hit coverage...” -> “...to provide hit coverage...” → ok
1. Introduction
- 46: “as innermost” → “as the innermost” → ok
 - 52 “..and up to a maximum...” -> “...corresponding to a maximum...” → ok

- 58-59: “LHC winter shutdown 2016/2017.” → “2016/2017 LHC winter shutdown.” (reads better) → changed to „LHC year-end technical stop in 2016/2017“ based on other comment

2. Design of the CMS Phase-1 pixel detector

- 81: “improving” → “improved”, in order to match the structure of the beginning of the sentence → ok
- 82: “adding” → “added”, same reason as above → ok
- 83: “for a placement” → “for placement” → ok
- 85: “radii of 29 mm, 68 mm, 109 mm, and 160 mm” → “radii of 29, 68, 109, and 160 mm” (consistent with style in intro) → ok
- 86: “291 mm, 396 mm, and 516 mm” → “291, 396, and 516 mm” (consistent with intro) → ok
- 90 The pixel detector -> The CMS Phase-1 pixel detector → ok
- 96: "a length" -> "a total length" (or similar) to avoid ambiguity between the combined barrel and the half-barrels → ok
- 113: “is needed” → “are needed” → ok
- 113: Don’t need “to be able to transmit”, just “to transmit” (clearer) → ok
- 122: Add comma between “layers” and “the” → ok
- 135: "foreseen during LS2": since it's currently LS2, you should be able to state with more certainty that it is happening during LS2 → changed to: the innermost \bpix layer will be replaced during LS2
- 138-140: Maybe split into two sentences → rephrased
- 142: “twice as large instantaneous luminosity” → “twice the instantaneous luminosity” → ok

3. Silicon sensor modules

- 148-149: Explain why they can only be placed "at some minimum distance", and specify that it is "from one another" → due to tolerances. Ok for the latter
- 158: "turbine geometry" → "turbine-like geometry" → ok
- 166: “had been continued” → “have continued” → ok
- 168: “detectors” not “detector” → ok

- 181: “of advantage” → “advantageous”; “allows to operate” → “allows us to operate”?, or some alternative phrasing → changed to: “which is also advantageous as it allows the sensors to be operated under-depleted”
- 185: comma after “sensors” → ok
- 185-186: "realized as large area implant" -> "realized as a large area implant" (or similar) → ok
- 186: “on” not “at” → ok
- 188-89: “allows to have” sounds awkward → changed to “The guard-ring scheme allows all sensor edges to be at ground potential,.”
- 192: "accumulation layer, that may short" -> remove comma → ok
- 212 “...on one...” → “...on each...” → ok
- 215: “are using” → “use” → ok
- 217: comma after “p-stops” → ok
- 218: "back side voltage": "backside" is used earlier in the paper instead of "back side". Not sure which is preferred, but it should be consistent. → ok, changed to backside.
- 218-19: “provide a connection of” → “connect” → ok
- 227: comma after “design” → ok
- 228: “close to square” → “nearly square” → ok
- 232: comma after “magnet” → ok
- 241: comma after “replacement” → ok
- Table 3: The formatting is different than e.g. Table 2. E.g. use of double lines. Also Table 4 and 5 → ok
- 253: "The pixel matrix": it would be good to specify here if this is relevant for both ROCs or just the PSI46dig → ok
- 258: it would be good to specify that "currently" is during Run 2 → left as is
- 260: "design of the pixel matrix remains essentially unchanged compared to the PSI46" → "design of the pixel matrix *for the PSI46dig* remains essentially unchanged compared to the PSI46" → ok
- 263: "namely +2.5V and +1.5V. They feed the digital and analog": respectively? → added
- 263: "circuit parts" → "circuits"? → ok
- 288: "Analog" -> "analog" (lowercase is fine here) → ok
- 295: “...noise at less...” → “...noise less...” → ok

- 295: "... a higher..." → "...higher" → ok
- 319: "to doses up to" → "with doses up to" → ok
- 329: should "to compromise" be "compromising"? or avoiding to compromise the data quality → avoiding any compromise in the data quality (or similar) → ok
- 332: "revised version of the PROC600": does the revised version have a new name that could be used as shorthand throughout this paragraph? → no name.
- 335: comma after "full" → ok
- 336: "does no longer acquire" → "no longer acquires" → ok
- 337: "going back to" → "a return to" → ok
- 351: Delete "in the revised version of the PROC600", it's redundant b/c of the previous sentence. → ok
- 352: No semicolon -- make it two sentences, or replace with a comma and transition wording → ok
- 355: TBM has already been defined and used in the previous section(s) → ok
- 361: Too wordy; "during the readout of a previous event" is all you need → ok
- 373: "semi independent" → "semi-independent" → ok
- 394-95: "to lose" → "losing" → ok
- 395: delete extra "of" → ok
- 407-8: comma after "TBM", "and it cannot" → "and cannot" → ok
- 409: "and it can only" → "and can only" → ok
- 412: "getting blocked" → "which would be blocked without intervention" → ok
- 414: "done" → "developed" or "designed" → ok
- 414: "in order to" → "to" → ok
- Table 4: this table should specify that Number of ROCs / TBMs / readout links are all per module, not total in CMS → ok
- 423: "feature also" → "also feature" → ok
- 423: comma after ROC, then "but use a TBM09 chip" and delete comma after "links" on next line → ok

- 428-29: re-word this sentence → left as is
- 444 comma after “thereby” → ok
- 448: Don’t need second sentence. “...five centers, and about 10-20%...” → ok
- 455: After comma: “the upgraded modules featured a detachable cable” → ok
- 460-461: Mention what benefit silicon nitride has over silicon (presumably that it is an insulator) → ok
- 484: “mid-80%” → “about 85%” (for clarity) → ok
- 493-495: Awkward. Maybe rephrasing as : “The gantry used for the module assembly steps is software controlled for both the gluing and encapsulation steps, leading to high reproducibility.” makes it easier to read? → ok
- 503: “have been” → “were” → ok
- 504: add “once at” before “+17C”. “In addition” → “additionally” → ok
- 524: add “and” after comma → ok
- 528: add comma after step → ok
- 534: “there is no response” → “there was no response” → ok
- 535: “Next, the trimming procedure was performed. This procedure aims...” → ok
- 538-39: Combine these two sentences into one → ok
- 539-541: Rewrite this sentence, it reads poorly → ok
- 560: “fitted by” → “fit with” → ok
- 563: “which is mostly relevant” → “most relevant” → ok
- 565: “Then” → “Next,” → ok
- 566: “makes” → “made”, “that allows to send a calibration signal” → “which allows a calibration signal to be sent” → ok
- 568: change to “air gap, and the generated...” → rephrased
- 568-70: “This way ... flagged as faulty” -- rewrite and combine into a single sentence → ok
- 571: “influences” → “influenced” → ok
- 575: “is determined” → “was determined” → ok
- 584: comma after “example” → ok
- 605: omit “of” → ok
- 617: “losses” → “loss” → ok

- “619: produced BPIX L2-L4 modules over time” → “BPIX L2-L4 modules produced over time” → ok
- 620: “...small number of 96 installed...” → “...small number (96) of installed...” → ok
- 620-621: change to “allowed module construction to start almost a year later...” → ok
- 628: “at the manufacturer” → “by the manufacturer” → ok
- Figure 15: The x-axis label on the left figure has weeks starting over from 0 in the middle. This is because it is the week of the year - but maybe it would be better to use the number of weeks from the start of the production? → prefer to keep as is to have this additional information.



4. Mechanics

- 662-63: change to “the opto hybrids are placed in Segment B” → ok
- 710 are -> were → ok
- 712: comma after “process” → ok
- 725: “turbine like” → “turbine-like” → ok
- 791 replace first “and” with a comma → ok

5. Readout architecture and data acquisition system

- 826: “programming, and clock and trigger distribution”: if this is referring to the PxFECs, remove the leading comma. Or use semicolons in this sentence for clarity. → ok
- 829: A bit odd to have this sentence as a separate paragraph? Maybe move this earlier and combine with e.g. first paragraph in Section 5? → instead combined with previous paragraph
- 862-63 Comma after “In addition” → ok
- 879 delete “Both” or insert commas accordingly → ok

6. Power system

- 935: Odd with single sentence paragraph → moved to L895
- 941: “plugged to” → “plugged in to” → ok
- 967-70: Split into two sentences → ok
- 1000 comma after “general” → ok
- 1001 add “some” before “DC-DC converters” because not all of them started to fail! → ok

7. Cooling

- 1043: Should be “condense”? → yes

- 1046: either “called an accumulator” or just “accumulator” in parentheses. Or “known as an accumulator” → ok
- 1080: change both “in between”s to “between” → ok
- 1083 “and supply ...” -> “and bypass valves for supply and return”? Don’t get the idea! → valves and bypass valves for supply and return, rephrased
- 1091: "as liquid" → "a liquid" → doesn't fit
- 1103: “has been” → “was” → ok
- 1105: “have been” → “were” → ok
- 1105-6: Rewrite this sentence → left as is
- 1118: comma after “detector” → ok
- 1126: “are determined” → “is determined” → ok
- Fig. 31 caption: “temperature measurements for ladder number 12 are affected...” → ok

8. Pilot System

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9. Integration, testing, and installation

- 1181 Comma before “further” → ok
- 1204 comma after “Then” → rephrased
- 1273: "mother boards" → "motherboards" → ok
- 1284-1285: “..the modules were placed on half-rings with vacuum holding jigs for the modules...” This repeats modules twice and makes the sentence awkward. → rephrased
- 1288: “practicable” → “practical” → ok
- 1297: “... found lost.” → “...lost.” → ok
- 1356: “relatively” → “relative” → ok
- 1356-57: “...using the reconstructed..” → “..using reconstructed...” → ok
- 1304 comma after “pixel detector” → ok
- 1307: “... the infrastructure of detector services was...” → “...the detector services were..” →ok
- 1315-16 Commas before and after “used previously” →ok

10. Detector calibration

- 1456: Formatting of “21 000” with a space is not consistent with formatting of other numbers, eg. “3500” a few lines earlier. → ok
- 1464: "pixel" → "pixel," → ok

11. Operation and performance

- 1488 comma after “subsequently” → ok
- 1492 comma after “Therefore” → ok
- Fig. 44: “convoluted” → “convolved” → ok
- 1514-15 merge the two paragraphs as they in direct relation → ok
- 1518: "Despite of the shift": drop "of" → ok
- 1524: "measurement" → "measurement," → ok
- 1566 comma after “in addition” → ok
- 1572: add a “the” before measured → ok
- 1604: comma after “Therefore” → ok
- 1604-5: Is carefully being → is being carefully → ok
- 1612: “which” → “that” → ok
- 1629: comma after “efficiency” → ok

12. Summary

- 1655-56: “absolute value of pseudorapidity of 2.5 -> $|\eta|=2.5$

13. Glossary of special terms and acronyms

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14. Miscellaneous Comments

- Abstract: “instantaneaous” misspelled, should be instantaneous → ok

Section-Specific General Comments:

1. Introduction

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2. Design of the CMS Phase-1 pixel detector

- 81: "improving pattern recognition and track reconstruction": state what this is improving with respect to, e.g. the CMS Phase-0 pixel detector → clear from context
- 83: "placement of the innermost layer closer to the interaction point": it would be nice to state how much closer (and that "closer" is with respect to Phase-0) → added radii to Figure 1
- 102: a nice additional detail to state here would be how many months the "extended technical stop in winter 2016/2017" spanned → added footnote

- Figure 1: this figure is really nice. One potential addition would be to mark the radii of the BPIX planes and the z-positions of the FPIX disks, if it could be done without making the figure too busy → added radii, z position don't fit.
- Figure 3: for the hadronic interaction length, the use of X/λ_0 seems unconventional since λ is typically used here in place of X . Also, it looks like part of the λ is cut off in the canvas → The label of x/λ_0 has been discussed extensively at the preapproval of these plots. The conclusion was that x/λ_0 is the preferred notation as x represents the distance travelled by the particle in simulation, which is then divided by the hadronic interaction length. The cut off in the label is fixed.
- Figure 3: Is this plot all simulation, for both Phase-0 and Phase-1? This should be mentioned in the caption. Also, some statement should be made about how well the simulated material budget agrees with data--does such a plot exist that could be included in the paper? → yes, all simulation. Added to caption. The comparison to data does not yet exist.
- 124-125: it would be nice to specify here what was used for the mechanical structure and cooling system in Phase-0, to motivate how these improvements were able to compensate for the increased material due to the additional sensor layers → prefer to keep as is

3. Silicon sensor modules

- 193: "n-side isolation": it would be nice to state whether this isolation completely mitigates the problem, or just reduces it to acceptable levels. → It solves the problem. We consider this common knowledge and prefer to not add any text here.
- 198: "small distances between the pixel implants": state how small → This is a general statement. Minimum distance depends on the alignment precision of the vendor. We used 20um which is not the minimum possible but a compromise not to have too high capacitances. I would prefer not to change the text.
- 220-221: "distance between the charge collecting pixel electrodes is larger compared to the BPIX sensors": state how much larger → About 50 um. Typically one does not mention such technical details in a paper. Such information is considered confidential.
- 223: "charge sharing between pixels is not caused by the magnetic field": what is it caused by instead in this region? incident angle? → rephrased
- 226: Ref. 12. Find it odd here that you have a reference to a paper from 2003 for this. Would e.g. Quality control of silicon pixel wafers for the CMS Phase-1 pixel upgrade KAMURAN DİLSİZ, SÜLEYMAN DURGUT, KAI YI, LEONARD SPIEGEL, Turk J Phys, 43, (2019), 541-550 be a more relevant reference? → added reference

- Table 3: The ROC size differs between the PSI46dig and PROC600. Should probably comment on this in the text? → we don't think this is needed as it has no relevant consequences for what is discussed in the paper.
- 228: "close-to-square": Could drop this, since a 2:3 aspect ratio isn't *that* close to square, and the rest of the details in this sentence remain true without stating "close-to-square" → ok
- 262: "overcome the limitations": which limitations? if it is only those discussed starting at line 283, this sentence can probably be dropped → yes, but still prefer to keep the sentence
- 320-321: "120Mrad, which is larger than the total dose expected during its operation in the innermost BPIX layer": it might help to clarify that this is larger than the dose expected when accounting for the replacement of BPIX layer 1 → ok
- 327-328: The second is a lower than expected efficiency, also at high hit rates": it would be nice to specify what hit rates and how low of an efficiency to give an idea of how severe of an issue it would be unmitigated (or already point the reader to Figure 7) → prefer to not expand on this at this point
- 349: "high-rate proton beam": since beam facilities used were mentioned previously, it would be nice to specify here too → ok, added (at PIF PSI)
- 522: "the optimal parameter was selected" -- maybe clarify what this means? Also possible that there's something obvious that I don't understand → rephrased. Means that a working point in the center of the valid region was chosen.
- 620-623: I'm not sure this information needs to be included → The reason to have it is to explain why in Fig. 15 the L1 modules are not shown.
- Figure 9: Very hard to see the protection cap in the figure. Any way to make it more clear? Close-up? → Visibility is ok, but maybe is unclear which one it is. So added sentence to caption: „The amber-colored protection cap covers the wire-bonds of ROCs and TBMs.“

4. Mechanics

- 724-743: Maybe split into two paragraphs, as this description is a bit long for a single paragraph. One focused on the mechanical structure and how sensors are affixed, the other focused on cooling. → ok

5. Readout architecture and data acquisition system

- 810: why four or seven? → as this was found to match both the fiber routing on the respective supply tubes. Prefer not to go in more detail.

6. Power system

- ➔ 887-888: You state the firmware and software was to change as little as possible. Why? → I think this is obvious, to reduce workload and risk. No change needed.

→ 890: “Since supply voltage stayed the same...” Refers to the voltage used by the ROC? Not the voltage supplied by the power supply. This is a bit confusing. Can you clarify? → OK, change to „Since the operating voltages of the ROC stayed the same”

7. Cooling

- Figure 29: Any significance for the factor of 1.43 shown for the maximal test pressure? If not, should that arrow be removed? → not in this context. Arrow removed.
- Fig. 30: I don't think this figure is necessary, as the image is too small/zoomed-out to resolve any interesting details. The setup is adequately described by the text. If it is retained, could labels be added to show e.g. the temp sensors? → agreed. Fig. removed.

8. Pilot System

- 1136-42: Rewrite these sentences if possible -- sounds odd as is. Don't need to repeat the phrase “the pilot system” so many times -- given the section title, no one is confused as to what you're talking about. Maybe just refer to it as “the system” → ok, rephrased.

9. Integration, testing, and installation

- There are several BPIX integration figures (Figures 33 - 36), but fewer for FPIX (only Figure 37). If the equivalent FPIX pictures exist, it would be nice to include them too. → ok, added three pictures of FPIX integration

10. Detector calibration

- 1445: "corrected": corrected meaning reduced? If so, is it reduced to a time-walk effect of 300e like the PSI46dig or something different? It would be good to specify this in the text. → Add a sentence at the end of this paragraph:
“In the new version the time-walk is reduced to the same value as in the PSI46dig, that is about 300 e.”

11. Operation and performance

- 1523: The word "track" is used as early as section 1, and is also used in the first sentence of section 11.2. Perhaps the definition of a track as a charged particle trajectory should be introduced earlier in the paper, maybe even in section 1. → indeed the definition is misplaced her. Removed.
- 1531: "week of collision data": Write the integrated luminosity, since a week of collision data from one period to the next can vary greatly. → Add at the end of the sentence “A full module level alignment ...”

“... of collision data which corresponds to an integrated luminosity of about XXXX fb⁻¹.”

- 1562: Clusters are mentioned earlier in the paper, so this definition should be moved earlier → rephrased.
- Figure 46: Expand on caption → Expanded to
- „Cluster hit efficiency as a function of instantaneous luminosity measure using tracks from collisions in 2018.”

12. Summary

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13. Glossary of special terms and acronyms

- PROC600, PSI46, PSI46dig: do the names signify anything? If so, it might be nice additional information in this glossary. → yes and no. For the original PSI46 is was just a version number. PSI46dig refers to PSI46. The meaning was only introduced for the PROC600. So prefer not to add it here.
- "Run 3: Third data-taking period at the LHC (2021-2024)": should have "2021-2024 projected" or similar → ok

14. Miscellaneous Comments

- Ref 35: More detail should be added in this citation, since the authors names are listed on the page and it provides a link for citation information (<https://www.nist.gov/pml/x-ray-transition-energies-database-version-history>). Similarly, all of the other link-only citations (23, 25, 26, and 31) should be fixed too. → ok
- Ref 66: Can theses be cited in papers like this? This link (<https://twiki.cern.ch/twiki/bin/view/CMS/Internal/WhatCanBeQuoted>) suggests that it is a "weak" reference, but may still be suitable here → kept.