Tk wide review: Comments by Hamburg University on the draft paper
"The CMS Phase-1 Pixel Detector Upgrade"

Dear authors, congratulations on a well written paper describing the design, construction and performance of the Phase 1 Upgrade of the CMS Pixel detector.
It is a real service to the community to compile this information in one paper.

The paper is well structured and reads nicely. We concentrated on chapters 3 and 10-12 in our reading, in the hope that others will have a critical look at the other chapters. Please find our comments below. They are meant to improve the clarity of the paper, none of them refer to serious problems.

TYPE B comments:
Chapter 3
L 153 vs. Table 3: 100 x150 vs 150 x100 - - >make it consistent → ok

Fig 3 caption: One sentence explaining the peaks for the Phase 1 detector material budget (i.e. the disks) would be good. → ok, added.

L188 This drift leads to charge sharing ◊ This drift leads to increased charge sharing (There is also charge sharing without this effect) → ok

L 196 ff: oxide charge is also present before irradiation directly after processing. Pixel isolation is needed from the beginning ◊rephrase sentence → oxide charge of a new sensor (after H-tempering) is ~1E10 /cm2 (for the <111> sensors) which increases to ~2E12 / cm2 with radiation. Therefore I consider the text correct. However changed to:

"The interface between the silicon substrate and the silicon oxide carries a slight positive charge which increases by orders of magnitudes after ionizing radiation."

L229 ff: FPIX sensor information much less detailed than for BPIX.
We suggest to compile a table with the relevant parameters for both → prefer to keep as is. Some of the information in the BPIX section is also relevant for FPIX. Also the sensor design is basically unchanged wrt Phase-0, so we prefer not to expand this section.

Figure 5 left: Looks like full dose p-spray and moderated p-spray are mixed up in the legend of the drawing → Indeed! Thank you for pointing this out. Picture is corrected.

Figure 5 right: arrow for Aluminum does not exactly point to Aluminum → Is not so easy. Al is overlaping. Picture is corrected.

L 438: IZM did not use Indium bump bonding but SnAg! ◊change → ok

Many places: change to SI Unit Rad ◊Gray → Kept, since it is more common to use Mrad. Same as in TDR.

Chapter 10
L 1390 Explain what is plotted against the delay, what plateaus? Reference Fig 43, otherwise the text is hard to understand → Not the same as Fig. 43. Rephrased to: "by performing a delay scan, chaning the phase of the programming data with respect to the clock. The region of correct phase is about 6-8\,ns wide and a working point in the middle of the valid region is chosen."

L 1395: what is the criterion for the choice for the gain → the gain is not optimized.

L 1400 why 0.1mA? → lower cutoff to have enough light at the input of the FED.

L 1406 The phases of the 160 and 400MHz clocks generated by the TBM PLL can be adjusted in steps of 0.4 and 1 ns, respectively ◊is it not 1 ns (for 160) and 0.4 ns (for 400 MHz), i.e. the other way around?
or should 400 MHz be 40 MHz? Please check → yes. Other way around. Fixed.

Section 10.4:

→ Most of the comments below would require a serious rewrite of the paper. We stress that this paper should not cover the detector performance, there is another paper planned which will concentrate on performance. This paper is about the design and construction. The performance part should be short, just for reference.

L 1422: What are the criteria to arrive at the lowest possible threshold? Please explain what was done. → The sentence "The strategy adopted .... " says it all. We simply adjust the thresholds to the lowest possible value for each ROC. ROCs stop working below this value.

L 1424 and 1426: standard deviation of 150-200 e … and average standard deviation per ROC of about 75-100 e
◊ Are these for BPIX and FPIX, respectively or is this spread layer wise? Please include this info
Add stat box to Fig 11 and refer to Fig 11 and the conversion factor such that the numbers are consistent and understandable → There are 2 different steps here. One is to adjust pixels within ROCs. This is done using the trimming mechanism, that is adjusting the 4 trim bits in each pixel. It should results in a uniform threshold with a ROC. This is what 75-100e refers to. The range corresponds to the fact that not all ROCs can be made uniform in the same way.
The 2nd step is to adjust the average ROC thresholds for all ROCs. Here each ROCs is adjusted to the lowest threshold that it can operate at. Therefore this procedure results in a larger RMS of 150-200.

L 1420
The lower the threshold, the more effective is the charge sharing, resulting in a better position resolution.

Change to something like: "The lower the threshold, the more the effects of charge sharing can be used, resulting in a better position resolution."

i.e. charge sharing itself is independent of threshold, only the effect on resolution changes → ok

L 1433
A subset of 81 pixels per ROC ◊where does the magic number 81 come from? How does the statistical error as a result of this choice compare to 100 e spread on the threshold?
→ The number 81 is quite arbitrary and was selected for time reasons. Measuring

thresholds for all pixels would have taken much to long. Too few pixels would have been statistically not representative. 81 is just right. But it also does not matter much if it was 100.

L 1440: After optimization in 2018 the L1 thresholds were about
2200 . ◊what was optimized? What was done, give some more details as this is relevant → It mostly has to do with the fact that we learnt better how to operate the L1 ROC. For example the programming sequence influences the cross-talk (noise?). Modifying the sequence led to lower noise, thus lower threshold. We could refer here to section 3.2 where the noise is mentioned in relation to it being reduced in the new PROC version.

L 1455 Please explain the concept of in-time threshold due to time walk in a bit more detail here and explain if the improvement after optimization is due to lowering the general threshold, or due to reducing the time walk → We cannot explain the whole time-walk concept here. This paragraph does not talk about time-walk. It talks about threshold optimization during 2018. Regarding the optimization we added the following sentence: "The main improvement was an implementation of a modified PROC programming sequence which left lines inside double-columns in low voltage states making them less sensitive to cross-talk during data taking.
Also we added a reference to 3.2 in the next sentence
" In addition ....lower cross-talk noise (see more details in Sec. 3.2)." and expanded the discussion of cross talk and time walk there.

Chapter 10.5.:
L 1460
-- > change sentence to:
The most probable value of energy deposition for normally incident minimum-ionizing particles (MIPs) in a silicon sensor with a thickness of 285 mm corresponds to approximately 21 000 electrons.
-add reference to this number → changed. No reference as this is textbook.

L 1462 deposited ◊ spread → ok

L 1463 An exact calibration of the pixel charge measurement...
==> An exact inter-calibration of the pixel charge measurements ... → ok

L 1466 The conversion of pixel charge measurements from units of ADC counts to units of electrons requires the calibration of the pixel response function.
==> This sentence I would move towards the end, before l1479 "The offline reconstruction..." → prefer to keep as is.

L 1467 The calibration is performed
==> The inter-calibration is performed → kept such that it matches the previous sentence

L 1476: Explain why pedestal variations influence the resolution more than gain variations → OK, rewrite the sentence in the following way:
"The pedestal variations have a stronger influence on the hit resolution than the gain variations. This is due to the fact that they can vary by hundreds of electrons while the slop variation is smaller and is also smeared out by the Landau fluctuations. Therefore for hit charge reconstruction ....in a double column"

Chapter 11:

L 1485 how is working fraction defined? As working channels, modules, chips? This is not clear from the text… → in terms of ROCs. Added.

L 1496
In the pixel detector system the granularity of the low voltage supply for the ROCs is finer than the granularity of the high voltage supply for the silicon sensor bias.
->not completely clear for someone who is not familiar with the system, we suggest to be more explicit:
" In the pixel detector system the number of ROCs supported by (or: connected to) one low voltage supply is higher than that of ROCs supported by one high voltage supply for the silicon sensor bias." → ok

L1501
Add "working":
building up a voltage difference at the input of the working pixel preamplifier which can cause damage to…
(to distinguish from the channel which is defective, where this would not matter…) → ok

L1504 6 out of 8 damaged modules (I.e. add "damaged)" → ok

Section 11.3
L1547: It takes more time: Be more specific on how much more time is needed → added (about 30s)

Section 11.4.1:

L 1559
what do the 10 % mean exactly? 10 % dead modules directly before reset?
What is meant by fill cycle? → Power cycles were only done between LHC fills. Until the end of the fill the fraction of dead modules in L1 increased to 10%.

L1564:
This calibration is used to express the charge in units of the negative elementary charge ◊what is explained here is only the gain equalization, whereas the calibration to electrons is done using monochromatic Xrays. ◊rephrase, and use the term "inter-calibration" (see 10.5) → Deleted the 1st two sentences in 10.4.1, so start the section with
"In the reconstruction step ..."
These 2 sentences do not bring much and are somewhat confusing.

L1569: unclear what is done with the Landau distribution in this context of charge calibration. Is the fit result used anywhere? Explain → No, this is just to say that the charge should have a "Landau like distribution.

L1581: explain annealing effects, esp on signal (which is much less obvious than leakage current). Also: what is higher temperature? We assume room temperature in this case → The annealing does recover some charge signal, we have seen it many times. The comment was added on a request of one of the ARC members.
However for simplicity we suggest to delete it. So just say:
"The charge loss caused by ... by increasing the bias voltage."

L1587: Asymmetric charge profile: What does this mean, be more specific, explain what is meant with strongly asymmetric → This just means the "charge profile" as measured

on the collection plane. The profile edge corresponding to the charge which travels from the other side of the sensor will suffer from
charge loss, the edge where the charge is generate close to the collection plane will suffer less.
This generates an asymmetry. This is what the Templates are about.
For simplicity, deleted this part of the sentence.

Figure 44: When were the charge spectra measured? State Integrated lumi in legend → Add to the figure caption the sentence
“The data correspond to an integrated luminosity of about 75fb-1.”

Section 11.4.2

Add a statement (or even a plot) how the Lorentz angle changed during operation due to irradiation.
Fig 45 is only for the beginning of data taking… → No. We want to leave this for the performance paper.

Fig 45:
-Add B field value in caption and state if this is for one module, one pixel, all modules in layer 2
-Y axis: change range to start at 0 → Changed caption to: “The plot is for modules from BPIX Layer 2 at the nominal CMS B-filed of 3.8T.”

L 1601: explain what production depth is and how it is obtained in one sentence to make paper self consistent independent of the reference → Added a footnote after “production depth” : (the depth in the sensor at which the charge was generated by the traversing charged particle).

Ref 66 should read Ref 68! → ok

L1613: How is the track defined here? → rephrased

L1612: “sensor efficiency” ◊it’s not only the sensor efficiency. Why not call it hit efficiency?
Define this hit efficiency and stick to one name → removed this sentence

L 1618: Please introduce the term “dynamical inefficiency” already in chapter 3.2. → REPLACE “ the so-called dynamical inefficiency” with “the ROC readout inefficiency”, it is not used anywhere else

L 1624 ff
Explain how efficiency is measured. What are the quality criteria? We assume known bad modules are excluded? → Added a sentence in line 1623:
“The efficiency is measured by propagating a track to the detector plane and checking if a hit is found on it.”

L 1624 ff (discussion of Fig 46) Explain why instantaneous lumi layers 1-2 have about 0.3% less efficiency than the other layers. This is probably linked to Fig 43 where it is shown that
the choice of timing setting is not optimal. Please make this comment more explicit in the discussion of Fig. 46. → As the text explain the dynamic data losses are very rate dependent. For the same inst. luminosity e.g. 10^34 the data rates in layer 2 are much higher than in layers 3&4.

Thus the efficiency is lower. If the plot was made versus data rates the curves would agree.
The fact that layer 1 is similar to layer 2 is accidental. Layer 1 has much higher data rates but also a different chip. Accidentally they compensate.

L1639: Ref 66, not 68! → ok

L1653: Why is the simulation worse? Don't call this agreement "very close". → It is very difficult to make simulation agree exactly with data. The simulation does not include many details of the real sensor (e.g. no electric fields). It is adjusted by smearing of various simulation parameters (e.g. noise, signal). This adjusts the simulation to one scenario, but would be wrong for another, for example if you adjust simulations to fit data in the middle of a year,
it will not fit exactly at the beginning or end. Note that CMS does not have a time-dependent MC yet.
Replace "very close" with "close".

Resolution numbers:
-Give numbers for all layers, including the disks, to demonstrate whether the extrapolation is as good as the interpolation method
-at which point in time are these numbers taken? Beginning of data taking, or after some radiation damage? → No, we do not want to do this in order not to double the performance paper.
Add to the figure caption in Fig 47
"The data shown corresponds to an integrated luminosity of 75\fb".

L 1645: Gaussian or Student T fit: which one is used? Which width is taken? Or is one function used for FPIX and one for BPIX? → Student T. changed.

TYPE A:
Style/ language comment:
L 400: "As a result of of adopting" repetition of the word of → ok