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TRK-15-002: Mechanical stability of the CMS tracker, as measured with its laser alignment system and with reconstructed tracks

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CADI

public plots DP-14-024

ARC reviews

G.Hall

* **Feb 29 2016 v0**

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Comments G.Hall

All text comments are included into *v1* of the draft.

* **March 23 2016 v2**

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I have not read TRK-15-002 v2 at all carefully but I see it has benefited from the comments so far, although I think fine tuning the English will continue to occupy us. However, probably now is the time to address more substantial issues. Some points which I have learned from Rainer and your responses are mentioned below. I am not an expert on the alignment methods and consequently may already be underestimating or overestimating the relevance of points which I have not properly understood.

The primary goal of this paper was the Tracker mechanical stability, where the LAS and track based alignment are merely the tools. That is why somewhat detailed description of the Tracker engineering concept, etc. Concerning the text, I immensely appreciate all language comments, it's really a pleasure to improve the text, maybe after next iterations it becomes readable...

Here are my main comments, some of which may seem to be naive. I believe I have understood the basic method but perhaps some fundamental points are not yet clear to me. Perhaps the overall objective should be emphasised more. I think this system ensures that we are not exposed to unexpected or impossible to understand changes in the tracker of mechanical origin, which would then be almost impossible for the other alignment methods to decode. So, this paper intends to demonstrate what precision was obtained and that big changes would be easily detectable. Is that oversimplified? Is there anything more? The fact that design objectives were exceeded is surely important and deserves attention?

That is right, and is not more complicated than that. The second goal of the paper is the LAS (we need this paper as a final report of the LAS performance, not just description of the system), so i tried to find a compromise without going much into details.

Do we believe the overall description is sufficiently complete? In general I thought so but there are a few

details: The reason for using tubes should be included in the paper, and any other constructional details which are important. There are not many actual images of the mechanical construction and indeed perhaps they are not needed. However, such figures which are present are very schematic (eg fig 3) and easily understandable by someone who knows CMS but probably less so for outsiders. Figure 2 is also familiar to us but not at all to outsiders. Do we consider captions to be adequate? How important is it to understand fig 1 and the possible movements? In the past, talks have been given which illustrate many points here described in words, eg sensor features. Would that help, at least to supplement descriptions.

There are many details indeed, but maybe for this paper better to simplify things and refer to existing papers? Concerning the description, suprisingly I didnt find publicly available compact overview of the Tracker silicon mechanics (there are details of different subsystems spread in different papers but not all together). The compromise we tried to reach.

I had not appreciated that the profiles in Fig 4 were from an integrated response. I had assumed that the laser amplitudes and duration were roughly similar to MIPs so the profile was the sum of 200 MIP-like pulses, all having a signal clearly distinguishable from background. (I probably knew this once but certainly had forgotten.) Unless I have not read it carefully enough, I donâ t think this is obvious from the text. It seems to me that it deserves to be made clear. I presume the signal accumulates but the background is effectively averaged, or fluctuations reduced. Can this be explained, as it is quite different from normal data acquisition? Should we be concerned, in view of the precision required and claimed, that the plots are not â simpleâ smooth Gaussians and in some cases include subtle diffractive effects which are mentioned but relatively casually dealt with. Can the signal amplitudes arriving at different sensors be described quantitatively (eg electrons, with laser pulse duration and even shape), or relevant examples given? Should the source laser pulse actually be illustrated? Does it vary throughout the system as a consequence of transmission? (I mean in time, as the amplitude obviously does).

Yes, in the offline analysis 200 pulses are integrated to increase S/N, I thought it is written in the text. Concerning the concerns. Before building the LAS many RD studies have been done and documentation exists (eg. PhD B Wittmer and couple of master thesis in Aachen are fully concerned to this). What is not clear for me how deep we have to go in there, provided the initial goal of the paper... What I can do prehaps, to prepare a list of additional plots on LAS performance that you may decide to include into the paper?

Consequently, the question of laser and background stability over the duration of the intervals over which the pulses are delivered surely needs to be mentioned? ie amplitude and individual pulse duration, at the source, as well as at the sensors. Transmitting light down fibres and viewing unfocussed images has potentially non-trivial consequences. Are the fibres so rigidly mounted that their position, or the light spots, are completely stable? The point about establishing the precision of the laser position (of 2-5 um and 5-10 um, leading to even more precise alignment parameters cited in Table 1) seems an important one, which again I am not sure I yet fully understand. I also found it difficult to know what to conclude from the plots in Figure 5 and 6. As well as natural spreads there are excursions which I cannot judge. I would benefit from being talked through the plots to understand their significance, which might also lead to suggestions for possible improved captions or explanatory comments.

The Figures 5,6 are the most important ones. I can not say we understood all variations (e.g. below 20um) but still it shows overall level of stability and reasons for variations. Certainly with some generalization, we are not going into details of each parameter. etc enough to show the range of variations. According to engineers it was not obvious at all(though they didn't say it during TDR loudly) because of the continuous thermocycling. The main new result is the stability and the variations over time. This was not discussed in any previous paper. About the LAS precision; it was evaluated in the periods of stable running i.e. can be slightly underestimated(i.e better in reality) in case of some movements of the Tracker. Even for relative measurements, the obtained resolution is a challenge provided that everything can move in the Tracker, at the TDR time, 10um was expected(see first comment).

I suppose that fig 7-9 are among the most important. I do not think I really understand how the relevant

parameters are extracted. There are no equations or formulae. Are they needed? Should there be an appendix? Or references to CMS documents? Am I right that Millepede extracts a more complex set, so the importance here is that these simpler values agree with Millepede (so movements would have been detected), not that the actual values are adding information which Millepede did not provide?

I consider the comparison with mpede as an addition to the LAS because this study can be improved. Interesting enough, in run1 there were no systematical study of the long term stability of the alignment parameters with mpede(Rainer may object here), I hope the LAS stimulated this and in run 2 it will go further. Unfortunately all these impede studies are rather heavy and we do not have any manpower to elaborate on this, we use what we have. Nevertheless the variations in both methods are similar, and keeping in mind the main goal, they are confirming the statement about the Tracker stability. The details of reconstruction are addressed in the mpede citeded paper, I dont think we have to go into details of the well established procedure.

References. Rainer made some important comments. For the existing references:

There are a few typos and details which need attention. [1] CERN/LHCC [2] Is there a page number or doi for JINST? arXiv is not needed as well. [3] & [4] ditto [11] page no? [15] Is this really correct? [16] sufficient?

will correct in next version

* **June 02 2016 v4**

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My comments are below. I think we are close to convergence, provided the alignment experts are satisfied, although I have raised a small number of substantial points in my reading. Most of the comments are tuning of the language. Geoff

The title is very long. I would shorten it a little to The mechanical stability of the CMS Tracker monitored using a laser alignment system [and reconstructed particle tracks] I wonder if the part in brackets belongs in the title, or if it is really used as a confirmation of the laser alignment?

the main subjects are: 1) Mechanical stability of the CMS Tracker, 2) the laser alignment system and 3)track-based alignment. The track-based alignment is described as a method similar to the LAS, though with less details, wish to keep it there. How to combine these three items in the title?

Abstract

1: delete various

2: fiber - US spelling is adopted, but be consistent. Elsewhere, you use centreâ, and fibre in a couple of places.

OK, switch to US spelling for center, fiber, etc...

4: replace a micron with μ appropriately qualified (e.g. approximately, or ~, etc)

9: were observed to experience movements, typically of around

OK for above

11: I would replace that are largely recovered. Perhaps that largely revert to their original values? Im still unsure about largely.

Modifed: Temperature variations are found to cause displacements of tracker structures of about 20$\mum$/10$^{\rm o}$C that largely revert to their intial positions when the temperature is restored to its original value.

12: The last sentence is a little vague. Perhaps:These measurements provide important guidance for future operation and upgrades.?

Modifed: These measurements provide important guidance for future operation and upgrades.

22: I dont think the operation requires cooling. Why not Silicon sensors exposed to a large radiation fluence require cooling? NB fluence'.

Modifed: Silicon sensors exposed to a large radiation fluence require cooling and the CMS Tracker is designed to operate in a wide temperature range from $-25^{\rm o}$C to $+25^{\rm o}$C.

29: A significant advance came

Modifed: A significant advance in the track-based alignment came with an introduction of the global χ^2 algorithm that combines reconstruction of the track and alignment parameters \cite{blobel}.

37: with a few days

38: time scales

39: with an optical

39: Lasers were already

41: also uses

42: of optical

43: in CDF

44: but lasers

49: a subset of 449 silicon modules [important, as there are far more than 449 modules in total!]

49: and monitor

54: procedure of using laser

ok for above

58: Below we discuss in more detail the components that are

Modifed: Below we discuss in more detail the components of the Tracker that are relevant to the mechanical stability of the detector.

72: allowing reconstruction

75: double-sided [and elsewhere, if

76: fibre?

ok for above

77: I think this should be reorganised? together with the readout hybrid ceramic, with a precision of?

Modifed: Each silicon strip detector module has one or two silicon sensors that are glued on carbon-fiber frames together with the readout hybrid ceramic, with a mounting precision of 10$\mum$.

85: Lorentz

106: A titanium

128: kinematic connections [is more usual]

142: I think C6F14 should properly be written with subscripts

145: The total Tracker

152: fluence

160: not sure what is intended but I would write with a cooling plant target temperature of -5

165: powering-on

Figure 2 caption: correspond to non-operational and red spots to closed cooling loops.

177: laser pulses

178: particles, thus

ok for above

178: I would reorganise to put The LAS uses the same.registration. before During physics operation

Modifed: The LAS uses the same detector modules that are used for particle registration. During physics operation laser pulses are injected into the 3μs orbit gaps in the bunch train of accelerated particles, thus not interfering with collisions. The laser beams are split into two sets.

186: internal TEC alignment traverses

191: and decreases by

ok for above

194: The laser spectral or, if you prefer, The spectral bandwidth of the laser

195: A coherence length longer than the silicon thickness would

ok for above

196: result in interference

Modified: The spectral bandwidth of the laser is $\delta \lambda$=2.4$\pm$0.9 nm that defines the coherence length L=$\lambda^2/\delta \lambda\approx$482$\mum$. The coherence length large than 2d/n$_{Si}$ (where d is the silicon thickness of 320--500$\mum$ and n$_{Si}$ is the refractive index) would result in the

interference of the laser light reflected on the front- and the backside of the sensor hence degrading the beam profile.

199: 0.125 mm diameter

Modified: ...via special mono-mode optical fibers with 0.125 mm in diameter...

212: collinearity as a function of beam

214: Since the laser light is

214: based on a

222: that reflect

ok for above

Figure 4. I think this is self-explanatory although you might add to the caption â More detailed explanations are given in the text.circular is misspelt on the figure, and fibre.

plot is corrected

230: in the TEC

230: sensors illuminated on their strip surface are standard detectors

231: while the 353 TEC sensors are

232: the backplane

234: in a 10 mm diameter circular

OK for above

235: Attempts to [are you saying that this was therefore abandoned? If so, make it clear.]

Modifed: Attempt to coat also the strip sides resulted in changes of the silicon sensor properties and this was abandoned.

239: APV25. This should be accompanied by a reference. The CMS JINST paper might suffice, which describes the full readout system. I think this should be referenced in any case, as the TDR [1] is quite dated. The reference is The CMS experiment at the CERN LHC The CMS Collaboration 2008 JINST 3 S08004 doi: 10.1088/1748-0221/3/08/S08004

added

Were the laser calibration runs taken in APV25 deconvolution or peak mode? I assume the latter.

During collision runs we run deconvolution, cosmics with peak. Most of data are in deco mode. I didnt put this into the paper, perhaps to much details.

240: It would be better to say digitised by ADCs on the Front End Drivers located [I dont think ADC needs expanding]

perhaps to much details about FED? better to remind what ADC means here, can be eg. advanced desing concept, etc...

241: and is processed similarly to

The analog signal from the APV is digitized by the analog-to-digital converters (ADC) located in the CMS control room and is processed further similarly to physics data.

243: I think a further explanation of the aggregation of laser pulses is required. I would suggest inserting a short paragraph at this point. Perhaps something like (you should expand): However, there is one significant difference in the handling of laser pulse data compared to that from particle tracks, which is that, in the case of lasers, the pulses are not measured individually but summed using the analog information. etc etc.

The reason for this should be made clear, and how it is done, including the impact of the pulse width, and the consequence on the data values, unless this is explained later, which I dont think it is.

there is some explanation in the next section, where the laser profiles are shown. Not obvious that further explanation will make things more clear for the technical people who maybe more intrested in this.

251: I dont quite follow this explanation. At line 177, it was explained that the laser pulses are injected into 3us orbit gaps and dont interfere with data taking. How is a 20s acquisition step compatible, and why does this increase to 5 min? What determined the 100 Hz rate? Could you be clearer about the different laser settings? Is it the amplitude which varies, to vary the illumination intensity? Is this why only 200 of the 2000 triggers are suitable for each module?

There are a few aspects: The acquistion interval is forced to 5 min (can be almost any), to have reasonable data flow and LAS time discretization. The 100 Hz is the laser pulse frequency, to cope with the DAQ bandwith (can be higher in principle, but is similar to random trigger and other calibration triggers) The 3um gap is used is a gate, to enable the laser shot, so not exaclty 20 sec (2000*10ms) for each step, depending on phase. Modified: ..... During physics operation laser pulses are injected into the orbit gaps in the bunch train of accelerated particles, thus not interfering with collisions. The 3μs orbit gap corresponds to the 119 missed bunches in the LHC beam structure that has the orbit time of about 89 μs. ..... The lasers are triggered in the orbit gap every hundred LHC beam cycle corresponding to a rate of 100 Hz and resulting in about 20 sec per acquisition step.

also added last sentence: There are five settings available for each laser, to be shared between up to 22 detector modules illuminated by the same laser beam. This results is some variations of the laser signal in different detectors.

270: the the

271: Relative displacements with respect to a reference

277: statistics

285: from the reference positions

286: values

288: the definition

290: while movement in the z-direction

291: the barrel due to the orientation of strips along

292: due to the radial orientation of TEC strips

298: the laser beam

299: due to temperature variations in the alignment

301: in the ϕ

304: assumption of

306: LAS components do not affect

314: light passes through the

OK for above

317: I can see that the resolution ought to be sub-pitch level, but I cant easily see how the values of, e.g. TIB, 2-5 um arise, when I look at the plot in fig 5, for example. Can this be justified further - perhaps in a footnote in the references? Was this explained in the discussion with alignment experts?

The meaning of resolution here is similar to the hit reconstruction accuracy in case of particle tracks. The COG method there gives better than pitch/sqrt(12) accuracy. In case of LAS situation is better, different methods tried, the FWHM slopes methods worked the best. The accuracy estimation (2-5um) for individual measurements can be estimated analyticaly (see lasresolution.pdf). But also is coming from the fit error matrix, the results are consistent. Obviously there are many details in this area, I'm not sure we have to jump in there.

330: the stability

334: A summary

OK for above

334: their stability In this paragraph, how is stability defined? I think it would also be helpful to include the meaning of this in the Table 1 caption, as well as some comment over what period(s). The caption refers to periods, but there is only one number for each quantity.

In the text: ...The stability of alignment parameters reconstructed with the LAS has been studied during periods of operation at fixed temperature where we expect no real movements of tracker components... Do you think this is not good? Added: The stability is defined as one standard deviation of the distribution of each alignement parameter.

337: is worse [but what does this mean? how can a rotation be compared with a displacement?]

The rotations corresponds to the displacements times lever arm. Removed, this is obvious.

339: A detailed

353: particle tracks

354: types of particle can

355: while the tracks from collisions mostly originate in

357: collision tracks

357: The samples are split into so-called

359: not include periods with significant variations in operational conditions but

365: can be represented as

367: caused to move for different

369: hours, and long term

369: or months

380: Interventions in

383: for validation of

OK

386: I dont want to be overly pedantic but it seems to me that the plots in Figures 6-10 show variations in parameters and the stability (or not) is inferred from them. Rather than describe them as stability plots, might it not be best to refer to variations of the alignment and then to comment on their stability? I do think some comment on the magnitude of the fluctuations in the captions would be justified, especially Fig 6. For example in Fig 6, variations in red are considerably larger than errors and seem quite large, over long periods. But this may be misleading, when looking at the subsequent plots. Does this deserve comment in the caption? Are green and blue data hidden by the red? If not, why are they not visible and centred on zero? Are there any obvious correlations, or do you wish the reader now to focus on the shorter periods in the next figures? I think this is the conclusion from the text from line 405 on. Perhaps the main point is that Figure 6 is the first the reader encounters, so they do not yet have the benefit of knowing what you say later about zoomed periods. Therefore, it would be wise to warn the reader how to interpret Fig 6.

Yes, this is overall look of the picture that is discussed in more detail later on. Added: Different parameters overlap in Figure \ref{fig:trackerlas} but the range of variations is clearly seen.

395: Periods with no LAS data occurred for

Periods with no LAS data are due to either non operational global CMS DAQ or to the non operational Tracker.

432: rigid bodies

433: same degrees of freedom

440: the statement about all transients being associated with temperature changes sounds quite important (or obvious?). Can we think of any other possible cause, which is now excluded, in view of your comment about other mechanical causes but only during access periods? Does this mean you have surveyed the data by hand to confirm that all variations were linked to temperature? Or have some method to look for correlations? Or does it mean that all anomalous changes are ascribed to some external event which can be identified? I am not trying to be super-critical but it seems to me that you are saying that this method demonstrates that unexpected behaviour of the tracker itself does not seem to occur - i.e. that its mechanical design is sound. Correct?

I can not be 100% sure that all movements are caused by temperature. Because: 1) some variations can

escape, I considered variations in dx, dy displacements above 10um,and checked the T variations. Indeed mostly by hand analysis,there are no clear criteria, there are many filters in the selection procedure to clean after bad acquisition steps, some cross talks, etc. 2) the correlations doesnt mean the reason (but is related, as said in the summary) 3) I assume that variations in dx, dy below 10um can be unrelated to temperature inside the Tracker.These can be external sources. However overall all parameters are rather stable during months of operation. This was not obvious. Keep as it is to avoid more modifications.

452: parameters change monotonically with temperature. When cooled by 5

454: Warming up eliminates most of the variations

455: residuals

466: temperature, variations of the alignment parameters were less than 30 um and larger changes were found to be related to temperature variations. [while this sounds very plausible, I am not sure it is proven by the data]

These large variations coincide with temperature variations, and I dared to assume their are related because of this thermocycling test But strictly speaking not all variations in parameters can be caused by temperature variations, though coincide.

468: are of order

468: are largely eliminated [Im not sure recoverable is the right word, but eliminated is my best suggestion, although it could imply action - but so does recover.]

OK

474: CERN LHCC As already mentioned, I think the CMS JINST paper is needed. Should not arXiv references be replaced by doi? arXiv is for preprints, while most of these are publications. [15] I dont think this is a satisfactory reference. Is there no manufactures data sheet to the specific lasers? [17] similar comment to above.

added the CMS JINST 2008 to bibl. For the diods, etc, there are no other official references exist except the web page. I saw this is used in NIM and JINST, eg in the JINST3, 2008 paper About doi, I see this is useless and not used in JINST refrences. Contrary the arxiv is very useful.

* **June 15 2016 v5**

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Dear Valery

Aa few more comments on the latest version which now seems quite polished and appears to respond to almost all my remarks. However, I do have a couple of more significant points which I hope you can explain easily.

thanks Geoff

TRK-15-002 v6

Abstract. I think my comment has been partly misunderstood. â monitored with a um resolution was not exactly what I intended. Perhaps monitored with $\sim 1 \mu$m resolution, changing \sim 1 to a few or the appropriate value? (10?)

from cosmic rays and collisions.

...monitored with a few $\mum$ resolution...

45: I would add a comma before hence

47 (and 173): radiation-hard

51: few μm

59: described in [1] and [15].

74: wedge-shaped

143: each with 40 kW capacity

179: missing bunches

OK, modified all above

192: is there really no better reference than [16]? Is there no manufacturerâ s data sheet, or similar link to the actual diodes cited?

this a commercial product, nothing except web page!

199: at the end of the sentence, should this be made very clear? e.g. profile; this is not the case[I only just checked!]

In the text: ...A coherence length larger than 2d$\cdot$n$_{Si}$ (where d is the silicon thickness of 320--500$\mum$ and n$_{Si}\approx3.5$ is the silicon refractive index) would result in interference of the laser light reflected on the front- and backside of the sensor, hence degrading the laser beam profile.... It looks obvious that the interference would affect the optical picture. There were a lot of lab study with different lasers, but I really doubt we should go into the detail.

217: does the name need to be capitalised?

this is a name of the company, but can be Phoenix Photonics, similar I did for the laser QPhotonics

226 and Figure 4: the figure legend refers to $S_1^{\prime}$ while the text refers to $S_I^{\prime}$. It would be easier to change the text.

OK

Figure 4: in the top diagram, I realise I am unsure about where the light enters via the beam splitter. Does it come in horizontally, or have I misunderstood? Maybe this needs clarification, as well as to include in the caption that BS stands for beam splitter.

there is a coordinate system on left of the BS. I included in captions the (BS)

242: APV25 chip

243: APV25

257: it would read better as or internal alignment of both TECs.

OK for above

256: this paragraph. I think I have now understood the rates. Perhaps the 100Hz should be adjusted to 112 Hz (if my calculation is correct) or to â about 100 Hzâ ?

I also found the description of the readout to be quite clear now, and I see the summation of multiple pulses is mentioned later, in the Figure 5 caption and the text. However, do you think that the reader should be given some indication of the signal to noise ratio(s) for the individual laser pulses, which presumably covers a wide range? Or the amplitudes compared to MIPs? The noise levels experienced do not seem to be mentioned at all, unless I am mistaken. To me this seems an important point of information, since the 50 ns duration of the laser pulses is much longer than most MIP signals.

The signal to noise for shot is about 1-2 and increases roughly as sqrt(Nshots), i.e for 200 shots it was above 20. I added last sentence: ....Thus for each illuminated module there are 200 suitable laser shots that are used to reconstruct the position of the laser beam in this module, as described in the next section. The signal-to-noise for the 200 accumulated pulses is above 20, which is similar to the signal from particle tracks....

304: what is j-laser I think this should be of the jth laser beam

OK for above

321-322: I still find this argument a bit difficult. I have not tried to derive the square root relation but I imagine it follows from interpolating a Gaussian profile in steps of m. However, that does not seem to allow for an imperfect Gaussian, either from statistics or noise. I can see from the profiles that the data are nor perfect Gaussians. The data are not plotted in steps of 1 strip either. So can I believe the 2-5 um quoted, etc? How crucial are the numbers quoted to the conclusions? Can you provide another argument to support them?

I am also a little unsure how to relate these numbers to the even smaller numbers quoted for stability in Table 1.

The resolution for single profile is an estimate, therefore not exact number but the range. The central part of all profiles can be approximated with the Gaussian, so the sqrt dependency will hold. The stability numbers in the Table are related to the reconstruction parameters, each calculated with many measurements, so one can expect much better resolution. There are two main cross checks. First is the chi2 of the fit when using this single profile resolution for each measurement. It was about one (I didnt discuss this in the paper, this will introduce signifcant discussion) and actually the errors on each parameter are in the LAS plot. Second is the stability of the measurements during'stable' periods -what is preseneted in the Table, therefore these single measurements number are not related to the final conclusions.

358: tracks from collisions

391: 5 minute LAS [I know English is illogical sometimes!]

399: non-operational

Figure 7: Expanded view

434: and TEC subdetectors

OK for above

R.Mankel

* **March 8 2016 v0**

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General remarks (v0):

The smoothness and accuracy of the language need to be improved in many places. At this point, I refrain largely from language or Type A comments & restrict myself to matters of the content itself. (This statement refers to v0, not to v1 which includes Geoff's improvements.)

Title: I would streamline the title. Perhaps Mechanical stability of the CMS tracker, as measured with its laser alignment system and with reconstructed tracks

OK

Plotting style: of all the trend plots, Fig. 7-9 are the easiest to read because the graphs of the different alignment parameters are shown in different sub-plots. Figs. 5-6 and 10 suffer from some graphs being obscured by other graphs. Readability in black & white print will very likely be a problem as well, also for Fig. 2

used the approved plots. Tried different presentations and there is a compromise to compare different parameters and subdetectors.

The references clearly need to be brushed up. In such a paper, the introductory part should give a clear description as to where we stand in the field, and contain references to all the relevant literature. This should include all alignment papers from CMS, certainly the comprehensive alignment paper with cosmics & collisions [2] but also the prequel from CRAFT, and I would also reference the muon HW-based alignment system (e.g. the journal papers of CFT-09-017, or even better MUO-11-001, or both.). I would also add publications on performance of laser alignment systems of other experiments, like this one from ZEUS: http://dx.doi.org/10.1016/j.nima.2007.06.046, and please check for relevant publications from ATLAS. Ideally one would cite a good review article, but I am not aware of one I could propose.

This is a nice suggestion to present a brief overview, will try to follow.

It is mentioned that the laser beams themselves move, but this movement, although said to be measurable, is not documented in the paper.

the movement of beam direction is described. Apart of this all small displacements of LAS components are not important for relative measurements if one assume flatness of all optical surfaces near beam spots.

Comments to specific parts of the paper draft:

Abstract: the abstract (v0) seems a bit too detailed, it should be streamlined. One could probably transport a similar amount of information with less sentences. Not sure what The sufficient temperature measurements... refers to.

OK

L20: better than 20% : where does this requirement come from?

initial requirements at CMS TDR time, accepted by eng. and phys.

Fig. 1 caption: How do the arrows show kinematic constraints? Can the subsystem move into the direction of

an arrow, or not?

yes, the allowed movements is shown, this is said in text: "...allowable movements indicated by arrows.."

L152ff: illuminating might not be the right word, since the laser light shines only through a small part of the sensor. Perhaps traversing would be better.

see v1

L154: Why are tubes needed at all in the AT? Explain.

see v1 improved. Tubes are needed to hold mirrors and splitters.

Fig. 2: contrast is poor with some of these colors

standard plot from the Tracker monitoring panel, hard to change

L173: How small is the coherence length, and what is the implication?

should compare coherence length with the size of components, such as thickness of silicon, mirrors coatings etc. If length is smaller/comparable will get extra interference. This was studied during RD phase.

L175: harsh conditions in which sense? Radiation?

temperature variations and radiation see v1.

L180: explain s and p polarizations

OK will do. Usual terminology in optics, s- Efield ortogonal to the incidence, p-parallel.

L209: This coating was applied... : It is not clear if this refers to the barrel or to the end caps

for TEC.

L233: The geometry model used for tracker alignment is hierarchical...

see v1, should be more clear

L234-239: Why are TID and Pixel not mentioned? Is this geometry model specific for LAS? The hierarchical model is not...

LAS was not used for them.

L247: References missing

OK

L264: constrained -> measurable ?

see v1

L265: but even with a reference subdetector, the TEC hit measurement would still be radial?

yes

L273: what has the beam spot position to do with the laser alignment, and how are the variations of the beam spot position estimated?

see v1, slightly improved. The laser beam spot position variations is the main 'observable' in LAS, the variations are estimated from the global fit as described in the text.

L301: Why is there only one offset and one slope per laser beam? Because the radial coordinate cannot be measured? Explain.

Yes, we use 2D r-phi coordinates for the beam as approximation, provided that the silicon sensor can measure only one coordinate.

Figure 4: what is the RMS of these profiles in microns? Judging by eye, about 100 micron e.g. for TIB? Does it lead to an entirely stochastic uncertainty? And after 200 dedicated laser shots for a module, is the resolution of the module position then RMS / sqrt(200) ~ 7 micron?

The profile is the integrated 'signal' after 200 pulses, for single pulse one see almost nothing. The fluctuations are mostly related to the detector noise (S/N). So there are no straight way to extract resolution from the profile RMS (if one measure stability of relative displacements).

L312: What does errors refer to? Is it the observed variation?

There are two possibilities to juge errors. The actual fluctuations of the laser beam position at stable conditions(noise and laser stability) and the fit errors that are related to the model(rigid body limited number of dof). In stable conditions conditions these two estimates should be and are similar. (with some caviats, eg we can not guarantee 100% stability, etc)

L315: The claim of a resolution of 1 micron for the TIB/TOB alignment parameters is very strong, given that the laser beam profiles are ~100x wider. Are there any convincing plots backing up this statement? Is this really the resolution, or more a measure of systematic stability?

The beam width is not really a measure of resolution. Important how well the stability of the profile can be measured, though narrow beams are better of course. The main argument that we have that such a resolution can be extracted from the stability of the reconstructed alignment parameters in the 'stable' periods, eg as shown in Fig 6. The sensitivity of LAS to movements was calibrated in the lab during RD phase but ideally one would benefit from LAS calibration in the assembled Tracker. Unfortunately It was never really done and initially foreseen. Partially the termocycling test we did and described was such a calibration(but we didnt have independent measurements, except Mpede that is difficult)

L329-342: In this section, I would recommend to adhere more closely to the description of the Millepede procedure as it is given in [2]. For example, the naming of the MILLE and PEDE parts is programming internals of Millepede, which may not be necessary to mention here.

OK

L352: this is very likely not a convergence issue of Millepede, which would sound like a technical deficit, but rather insufficient input data. Rephrase...

OK

L350-358: it would be good to point out here what is different or special in the use of MP for this paper. Are only higher level structures aligned, or does it descend to module level? (L357-358 seem to indicate very vaguely that only higher level structures are aligned. In this case, what module level alignment constants are used?)

The only difference from LAS was that the half cylinders were considered, i.e. TIB+, TIB- etc instead of the whole TIB. These halves were averaged. I didnt go into the details of Mpede, it would explode the text. The TOB was FIX in config similar to LAS, eg. TrackerTOBBarrel, FF0FFF, TrackerTIBBarrel, 110111.

L382-387: The whole 2011-2013 period can be split on different parts : But what are these parts? Are they contiguous areas in the plots, and can you mark them? Perhaps you should think of a kind of status bar with a color code on the plot which indicates which kind of part an interval belongs to.

The parts are not contiguous areas, I agree the word might be confusing but didnt find a good syn. I'd not change the already crowded plot but rather to explain it in text. In v1 it is slightly modified, maybe in better way...

Fig. 5: Why is the jitter so much larger than in Fig. 6? Do you claim there are real movements causing this, even though the temperature seems rather stable most of the time? Or did you just pick a particularly nice period (with small jitter) for Fig. 6?

The Fig.6 just zooms (in time) some particular 'parts' we have discussed.

Fig. 5: It is difficult to understand which conclusions can be drawn from these plots. Near the left edge there is a positive temperature spike, and a subsequent upset in the delta-x alignment parameter, but there must be O(10) days in between? In early Sept 2012 there is a large excitation in the LAS alignment parameters without apparent reason. Can one point out at which points in time the reference values of the LAS have been reset?

All variations in LAS data are associated with temp. variations, and some examples are explained in Fig6. I didnt go through all of the them. Some reference periods are shown in Fig 7-9 in comparison with mpede. In the text ii is said that new reference is selected after variations of conditions. Between these variations the jumps in LAS parameters(if using one single reference in 2011) can be about 50um. Since LAS measure short term relative variations, one can select reference almost at any point during stable period (but the pattern of variations may change in this case). So the choice of references depends upon the goal. I think we dont need this discussion in the paper.

Fig. 6: only delta-x (the red filled circles) is well visible.

L 388-394 + Fig. 6: the apparent jitter of the points visible in Fig. 6 is stated to be within +-10 micron (TIB, shown) and +-20 micron (TOB, not shown). This jitter is attributed to the resolution of the LAS. Can this be reconciled with the previously stated LAS resolution of 1 micron for these parameters?

The resolution is the property of LAS to measure displacements, the jitter is related to the mechanical stability of the Tracker. From plots one can conclude that we do not well understand the movements under 20-30um. There are no obvious temperature variations or other variations I tried to spot looking on CondDB temp, all logbooks, and even local earthquakes. But it can be some escaped reason.

L395-396: Where can these effects be seen in the plots? Consider to put labels, like A , B etc to the plots, which you can refer to in the text.

see v1, a bit improved there.

Fig. 6d: it is not clear how the cooling plant shutdown is visible in this plot. The mostly prevalent temperature seems to be around 6 degrees (~target temperature?), and there are 1-2 departures to the higher & lower side. You should mark the switching on and off of the cooling plant or individual components in a similar way as in Fig. 6c.

LAS can measure only when the whole DAQ is restarted, so we see only tails of the events. The information, what actually happened is taken from logs, etc... With this understanding one can use the LAS measurements

to spot such events.

Fig. 6: Is it correct to assume that the reference position of the LAS has not been changed during this period? State clearly.

We are not controlling position of all LAS components. The main assumptions are: a)small rigid body movements of Tracker and b)allow rotation of laser beams but c)assume flat surface of optical components near the laser beam. So laser beam can move, i.e beam splliters can move, the mirrors in AT can move correlated together with the whole tube, etc.

L416: Given that Millepede is a complex program with many options, it would be good to state in which way it has been used. Did you align large structures only or module level? How are the errors deduced from [2], are the alignment mode and number of events compatible?

Obviously in this paper we rather refer to published papers with tracks alignment and would reduce related text rather than add more information of Mpede. Since I am not an expert in Mpede, this part has to be modified by M. Schroeder, I'm not sure he has time. Would be grateful if you can point out to comprehensive description I can include or, better, to refer.

Fig. 7: One notes that e.g. for delta-x, in the beginning LAS is systematically higher, while later the LAS and MP values agree quite well. Can this be understood somehow, e.g. with resets of the reference position in LAS, or is it just a discrepancy of trends?

Fig. 7: One also notes that the error band of MP is much larger than the apparent variation of the points.

Fig. 7: It is a pity that there is no coincidence of structures visible, apart from a certain degree of stability. And the MP points are certainly not dancing around as the LAS points seem to do. Do we attribute this to the poorer time resolution of the MP measurement which smoothens out genuine structures, or to the jitter of the LAS measurement?

In the text it is said the Mpede measure absolute displacement, LAS measures relative, so the gradients and variations should be compared, not the systematical offsets. The errors in MP is just anticipated as in the referred paper, it was no error evaluation in this MP runs. The differences in LAS and MP are within errors and overall stability of the Tracker is similar for both measurements. Note that the MP measure displacements of all modules in TIB, TOB, TECs and the LAS only the illuminated modules. I agree that the individual fit errors in MP(not calculated) are probably smaller and provided the LAS errors (as shown) one may see some differences in some periods. However the detailed analysis of this is complicated and was never been done, unfortunately. We also can expect the non rigid body movement in the order of differences. The only conclusion I'd draw that MP and LAS have similar scale of fluctuations, that is, the Tracker is stable within 20-30um.

Fig. 10: Over which periods have the cosmic tracks for MP been accumulated? This is an important piece of information when judging the comparison. The Ry comparison is quite a bit off. What does it mean that the Ry rotation ... is weakly constrained by the mechanical design ... is the difference within the expected uncertainty? It is odd that the +4 degrees legend is above the graphs, while the other temperature labels are below.

It was only ~20000 tracks from about 20 hours during thermocycling test. MP has converged but no errors analysis. Therefore we didnt expect perfect agreements. The dy and partially Ry are constrained by the detector weight only. However I think in this case the Ry was weakly constrained in the MP fit because Tracker was not fully assembled; only barrel cosmics trigger were used. I'll change the text.

L433-436: The conclusions from Fig. 10 are relatively modest. One could at least point out that there is a relatively continuous trend, i.e. each parameter increases or decreases monotonously with temperature,

correct? This is also implied in Fig. 11.

OK.

L437-438: One should add some conclusion from Fig. 11, for example to which degree the movement of the individual detector parts can be viewed as common, or different. Do we any idea from the mechanical point of view why they move differently?

I think to juge what is moving we would need a model. There is no model exist that can respond on temp. variations and I consider this is an important lesson learned as mentioned in the summary.

Fig. 11: Why not show delta-x and delta-y in one plot?

Fig. 11: The illustration of the rotation delta-Rz is unclear, since there is no marker on the circle.

I removed this plot in v1.

Summary: Only the first paragraph is really a Summary , and it is very terse. It would be good to summarize the main conclusions from the various result sections of the paper in more detail. The second paragraph of the summary brings something new. It might thus fit better into the body of the paper, and still could appear in a summaric sentence in the summary.

Agree.

References: This section needs to be brushed up, extended and homogenized significantly. Please give all references in proper style, author, title etc. For [2], please refer to the JINST paper, not the CERN report. For MP, please look at [2] how it is referenced properly.

OK

* **April 6 2016 v2**

More Hide

(*1) What can be justifiably stated as alignment parameter resolution of the LAS

(*2) The non-readability of part of the graphs in the stability plots (Fig. 5-6), and conclusions from these plots

(*3) The presentation and conclusions from the LAS/MP comparison (Fig. 7-9)

Concerning a possible meeting, I will be away from my mail during 11-18 April. I might be at CERN from 20-22 April but it is not certain yet.

Best regards

Rainer

Detailed list of comments:

L152ff: illuminating might not be the right word, since the laser light shines only through a small part of the sensor. Perhaps traversing would be better. see v1

> L152ff: illuminating might not be the right word, since the laser light shines only through a small part of the sensor. Perhaps traversing would be better."

> see v1

It is not improved in v1.

For the TEC this is traversing, for TIB/TOB this is shining, Jeoff proposed illuminating....

(*1) Concerning LAS resolution (=my comment to L315f and your responses):

> L315: The claim of a resolution of 1 micron for the TIB/TOB alignment parameters is very strong, given that the laser beam profiles are ~100x wider. Are there any convincing plots backing up this statement? Is this really the resolution, or more a measure of systematic stability?"
> The beam width is not really a measure of resolution. Important how well the stability of the profile can be measured, though narrow beams are better of course. The main argument that we have that such a resolution can be extracted from the stability of the reconstructed alignment parameters in the 'stable' periods, eg as shown in Fig 6. The sensitivity of LAS to movements was calibrated in the lab during RD phase but ideally one would benefit from LAS calibration in the assembled Tracker. Unfortunately It was never really done and initially foreseen. Partially the termocycling test we did and described was such a calibration(but we didnt have independent measurements, except Mpede that is difficult)

I doubt that this is a suitable definition of a resolution. You do not prove that, if there is an offset of X microns, then the LAS will measure a shift of X microns within this resolution. This would, minimally, require an absolute invariance (and knowledge) of the beam profile shapes as a function of the offset. Looking at the beam profiles in Fig. 4, one may doubt that these profile shapes are absolutely invariant and independent of the value of the offset to be measured. For example, during a sliding shift across an interval of 1 readout pitch (120 micron in TIB), the slide across the strip pattern alone will lead to a change because of the finite strip width. And for the diffraction pattern in the TECM plot, do you think you can claim that this is independent of the offset, and other influences. Another question: is the variation of the ADC counts of each strip across the step number explained by statistics, or are there other systematic influences? In summary, I think you could claim stability at the micron level at times, when the LAS measurements do not change by more, but the claim of a resolution at this level might be hard to justify.

Concerning the "resolution". In principle I agree that what we measure is not a resolution but rather a sensitivity to the variations. However I tried to keep the same terminology as for the MP. In MP the resolution is extracted from the Lhood fit to the data using residuals and some physics constraints(eg. Z width etc), that is, the resolution is a measure of the chi2. Similar, the LAS does the fit and calculate the chi2 which is about 1 assuming the resolution in offset parameters of about 1 um, as stated in the paper. In both methods there are no "hardware" check with the induced and reconstructed displacements that can be compared. For the LAS the stability of parameters during the stable operation is a good prove of the 'resolution'. To conclude, I'm not against to replace "resolution" by "stability" but afraid this will bring more confusions to the external readers. Please let me know if all ARC members agree on that...

L 313: How large is sigma_b?

L 321: You should motivate/explain this formula (also in the text). It looks as if the reconstruction accuracy for the individual laser beam position might be much smaller than the hit resolution if sigma_b is very small. Naively, one might rather think of a different formula, like sqrt(pitch**2 / 12 + (sigma_b)**2).

The width of the beam profile is shown in the plots and depnds on the detector, typically about 1mm. The derivation of the formula is rather bulky, see lasresolution.pdf

(*2) Figs. 5-6: There is still the problem that part of the graphs cannot be seen properly in Fig. 5-6, because of significant overlap.

The plots are illustrating the stability, we are not going into details how much each parameter is varying. The

alternative would be to split these plots, not a problem. But do we really need it?

> *Fig. 5: It is difficult to understand which conclusions can be drawn from these plots. Near the left edge there is a positive temperature spike, and a subsequent upset in the delta-x alignment parameter, but there must be O(10) days in between? In early Sept 2012 there is a large excitation in the LAS alignment parameters without apparent reason. Can one point out at which points in time the reference values of the LAS have been reset?"*
> All variations in LAS data are associated with temp. variations, and some examples are explained in Fig6. I didnt go through all of the them. Some reference periods are shown in Fig 7-9 in comparison with mpede. In the text ii is said that new reference is selected after variations of conditions. Between these variations the jumps in LAS parameters(if using one single reference in 2011) can be about 50um. Since LAS measure short term relative variations, one can select reference almost at any point during stable period (but the pattern of variations may change in this case). So the choice of references depends upon the goal. I think we dont need this discussion in the paper.

In other words, there could be changes of ~50 micron that would not be visible in the plots?

Yes, there are some offsets 10-50 um after TS for example when Tracker is off. This can be the LAS components and the Tracker components, we do not know, and in the paper is written that the abosulte LAS resoultion is about 50-100 um.

> *L416: Given that Millepede is a complex program with many options, it would be good to state in which way it has been used. Did you align large structures only or module level? How are the errors deduced from [2], are the alignment mode and number of events compatible?"*
> Obviously in this paper we rather refer to published papers with tracks alignment and would reduce related text rather than add more information of Mpede. Since I am not an expert in Mpede, this part has to be modified by M. Schroeder, I'm not sure he has time. Would be grateful if you can point out to comprehensive description I can include or, better, to refer."

Concerning the MP study, I learned from Matthias Schröder that he did it on the basis of high-level structures, like BPIX layers, TEC half disks etc, using isolated muon, minimum bias, Zmumu and interfill cosmic datasets, with several IOVs.

I would thus change the text in the following way:

- at the end of the first paragraph in Section 4.2, insert: For the study shown in the following, MILLEPEDE was operated in the mode with large-substructure parameters, as described in Section 4.3 in [4], to match the granularity of the LAS alignment. For example, XX parameters were used for the whole TIB, similar to the LAS .

- Delete the bracket sentence in L 357. Insert the correct number for XX, and check with Matthias if really XX=5, or rather XX=6, which is more natural for MP.

OK

> *Fig. 7: One notes that e.g. for delta-x, in the beginning LAS is systematically higher, while later the LAS and MP values agree quite well. Can this be understood somehow, e.g. with resets of the reference position in LAS, or is it just a discrepancy of trends?*
> Fig. 7: One also notes that the error band of MP is much larger than the apparent variation of the points.
> Fig. 7: It is a pity that there is no coincidence of structures visible, apart from a certain degree of stability. And the MP points are certainly not dancing around as the LAS points seem to do. Do we attribute this to the poorer time resolution of the MP measurement which smoothens out genuine structures, or to the jitter of the LAS measurement? "
> In the text it is said the Mpede measure absolute displacement, LAS measures relative, so the gradients and

variations should be compared, not the systematical offsets. The errors in MP is just anticipated as in the referred paper, it was no error evaluation in this MP runs. The differences in LAS and MP are within errors and overall stability of the Tracker is similar for both measurements. Note that the MP measure displacements of all modules in TIB, TOB, TECs and the LAS only the illuminated modules. I agree that the individual fit errors in MP(not calculated) are probably smaller and provided the LAS errors (as shown) one may see some differences in some periods. However the detailed analysis of this is complicated and was never been done, unfortunately. We also can expect the non rigid body movement in the order of differences. The only conclusion I'd draw that MP and LAS have similar scale of fluctuations, that is, the Tracker is stable within 20-30um.

So you take the MP errors from the paper, which refers to alignment at module level? Since MP has been run for high level structures for the study in your paper, the alignment parameters e.g. for the whole TIB are much more precise than that, if track statistics is comparable. This makes the error bars of the MP points not very meaningful. And where do you take the MP errors for the rotations from? I am not aware that rotation angle precisions are given in [4], let alone for whole subsystems.

Yes we do not have a real error analysis for the large structures in MP. There is an alignment paper and the CMS-AN-12-235 from J.Hauk about resolution that I used. I do not think the MP resolution with big structures will be much better though, the errors bars I used for the individual models are the conservative estimate for big structures. The conclusion from the LAS+MP stability plots is obvious: the parameters are within the stated range as written in the summary. I do not see what else we can extract from them. Unfortunately there are no detailed comparison of two methods available (hard to do), also there are no mechanical model that can be used to illustrate the observations(should be done)...

References:

[3]: Is the title wrong? The CRAFT paper did not use collisions.

[2],[3],[4]: Starting page number missing

yes, you are right, will correct

* **June 3 2016 v4**

More Hide
Dear all,

thanks to Valery for producing this new version of the paper draft, which I think constitutes considerable progress. My impression is that the major content-related issues have been resolved, and that mainly aspects of wording and improving the correct understanding remain to be addressed. I enclose my comments below.

Cheers Rainer

Type B comments:

- Title: I fully agree with Geoff s proposal for shortening of the title.

see comment to the GH [GeoffHall02062016]. I do not see how to keep: Tracker Machanical stability, laser alignmnet system and track-based alignment together in a shorter way. tried: Mechanical stability of the CMS Tracker measured with the laser alignment system and particle tracks.

- Abstract: still too long and too detailed. For example, the first sentence could be removed or shortened.

removed: The laser system monitors the relative movement of large substructures...

- L 25: that tolerates some thermal expansion : this sounds very arbitrary. I am sure that the engineering design is such that it tolerates all thermal expansion that can be reasonably expected

Modified: The mechanical stability of the tracker components is ensured by the choice of materials and by an engineering design that tolerates expected thermal expansion and detector displacements.

- L 35: with a few million specifically selected tracks of different categories

Modified: For example, an accuracy of about 10$\mum$ for individual modules can be achieved with a few million specifically selected tracks of different categories that can be acquired in a few months of operation.

- L 35-37: I would be careful about hard statements concerning how many days/months track-based alignment needs. I think we want to say that the times are macroscopic compared to LAS, and range from day to months depending on the level of detail in the alignment parameters. (In the prompt calibration loop, alignment of a few relevant parameters is done within hours.)

L36-37 removed modified L280: For example the alignment of large structures, similar to LAS, can be performed in a few hours of data-taking.

- L 42: Since you mention the RASNIK system, a short half-sentence alluding to its measurement principle (imaging of an illuminated mask pattern if I recall correctly) would be in order.

can not explain it in short sentence better than in the given reference

- L 163: but there seems to be no red spot in the TOB?

some in TOB L3

- L 170: The initial purpose : has the purpose changed in the mean time?

yes. initially planned to use LAS for absolute pre-alignment with 100um accuracy before cosmic commissioning and relative measurements with about 10um. Then the cosmic alignment did much better than 100um and the relative LAS measurements also did better than 10um but about 1um.

- L 195: relatively small : Is that good? Explain more clearly.

Modified: The spectral bandwidth of the laser is $\delta \lambda$=2.4$\pm$0.9 nm that defines the coherence length L$_c=\lambda^2/\delta \lambda\approx482\mum$. The coherence length much large than 2d/n$_{Si}$ (where d is the silicon thickness of 320--500$\mum$ and n$_{Si}$ is the refractive index) would result in interference of the laser light reflected on the front- and the backside of the sensor hence degrading the laser beam profile.

- L 235-236: attempt : what does it mean, are the strip sides coated or not?

Modified: Attempt to coat also the strip sides resulted in changes of the silicon sensor properties and this was abandoned.

- L 252: The 1000 triggers : which 1000 triggers, since you previously mentioned 2000? The first 1000 of the 2000, or just part of the 2000? - : how is it optimized? Which aspects have been tuned?

the optimization is described in previous paragraph. Modified: One regular LAS acquisition step consists of 2000 triggers fired with different laser settings. The first 1000 triggers are optimized for the global alignment, and another 1000 triggers are used for the internal TECs alignment.

- L 256: does it mean one full measurement cycle every 5 minutes? Please clarify in the text.

in the text: ..During normal data taking the acquisition interval was set to 5 min to achieve a good compromise between the time resolution of the LAS alignment and the stored data volume... is this not enough? this part is slightly modified according to GH comments.

- L 276: copiously produced in CMS sounds awkward in context with cosmics, which are by no means produced in CMS. Perhaps --> ... are recorded in large quantities in CMS...

this sentence was already suggested by somebody, would keep it...

- L 277: statistic : rate?

statistics

- L 298: we assume that the laser beam moves as a straight line : it is not at all clear what you mean here. Do you mean the propagation of the light, or the movement of the lasers as the detector moves?

means that the laser beam direction can change. The corresponding beam spot in each detector would move too, assuming that the direction of beam and the movements of detectors can be factorized in the fit.

- L 351: what do you mean by absolute ? Clearly this could be misleading.

removed ..absolute..

- L 355: mostly perpendicular to the beam pipe is not quite correct in two respects: (1) they tend to be vertical, not perpendicular, and (2) mostly is too strong a word. The angular distribution is such that vertical directions are more likely than horizontal ones. And another important feature of cosmic muons is also that they are not confined to passing through the nominal interaction point.

Modified: Different types of particle can be used; the cosmic muon tracks are mostly vertical while the track from collisions mostly originate in the detector center

- Fig. 7: Zoom -> Expanded view of selected time intervals

ok

- L 408: cut off sounds like slang. And here and in many other cases where you use terms like power down etc it is not clear whether the transition was intentional / scheduled or due to an operational problem. Use consistent and well-defined terms.

cut off ->powering down

- L 414: was only the LAS data acquisition restarted, or the whole LAS system?

LAS acquistion, here means the global run is started. The LAS system was always operational (except some occasional power cut in the LAS barack)

- L 430: with new references : so in each of these periods, LAS has a new reference?

yes

- L 434: again the question what absolute means. In view of the resetting of the reference for the LAS in each period, do you refer to the fact that the MP alignment parameters are absolute in the sense that they are

directly comparable to each other across the whole time window?

removed

- L 441: are related to -> coincide with ?

replaced

- L 441-443: the dedicated thermal model can be used in the future to predict... : this is a very strong statement! Has the proof of principle been made already? Otherwise, we might indicate more like a hope that this may be feasible in the future.

why? the thermal model is implemented in many projects and the exact displacements are predicted. In CMS it was a primitive estimate. Nowadays computing alows this. For monitoring purpose this is much simpler than building LAS. Personaly I think this is the main lesson: built an independent continiously running Tsystem and calibrate the movement with some forced heat sources. If it want be done in next runs, will be really pitty.

- L 451: acquisitions -> operations ?

replaced

- L 460: except for rotations : do you mainly refer to Ry here? The agreement for Rx and Rz seems to be satisfactory.

- L 461: The rotations were weakly constrained by cosmic muon... : it seems you argue here that a limitation of the track-based alignment is at fault. Is this an established fact, or just a speculation?

in this test only central part was triggered, so not enough lever arm to constrain the rotations. Modified: Both measurements are in reasonable agreement for all alignment parameters except for Ry rotation. This rotation was weakly constrained by cosmic muon tracks because during the shutdown only the central part of the muon system was used for the trigger.

- L 464: was successfully monitored ok

- L 463-471: I wonder if the summary could not be strengthened. You could e.g. point out again the fast turnaround of the LAS, and the fact that the system would spot large movements quickly and reliably if they were to occur.

maybe keep it as it is? The main result is the mechanical stability during operation at different temperature.

Type A comments:

- Abstract: ... were observed , ... are found : tempora should be consistent, also in other parts of the text.

modified: are observed

- L 14: make clear that this is the **momentum** accuracy

modified: The CMS Silicon Strip Tracker is designed to provide precise and efficient measurement of charged particle trajectories in a solenoidal magnetic field of 3.8 T with a transverse momentum accuracy of 1.5-10$\%$ in the range of 1--1000 $\GeVc$.

- L 22: fluency -> fluence

- L 23: in temperature range, use to instead of dash

Here and in general: for minus signs always use the (long) math mode symbol, not the short dash

ok for all above, modified

- L 26: accounted for in the form of alignment constants

- L 29: {2]-[4]

- L 29: Significant progress... (remove the

- L 33: depends on the

- L 39: The lasers : sound like they were the same devices, which is probably not true.

- L 43: in CDF

- L 66: rephrase, perhaps like of 2.4m in diameter

ok

- L 80: defined by the physics acceptance... : this is nebulous; explain what you mean.

modified: ..by physics requirements...

- L 142: C6F14: chemical formula, use proper indices

- L 177: laser pulses

ok

- L 178: thus not interfering with collisions. The LAS uses...

Modified: The LAS uses the same detector modules that are used for particle registration. During physics operation laser pulses are injected into the 3μs orbit gaps in the bunch train of accelerated particles, thus not interfering with collisions.

- L 192: is regulated by the operating

- L 201: is distributed to different subdetectors

- L 206-207: insert blanks before the brackets

- L 230: in - : compromising ... --> to achieve a good compromise between...

- L 263: The general Tracker alignment procedure

- L 269: are rather different

ok for above. Modified: The alignment procedures with particle tracks and usung the LAS data are rather different.

- L 275: remove last and

- L 288: the definition

- L 301: in the ... plane

- L 317: use a proper math symbol for the pitch. Reference for this formula?

ok for above. the formula is a bit cumbersome (see lasresolution.pdf). But this is clear from general assumption

- L 324: replace etc by its meaning. Ry and Rz?

- L 328: is flexible;

- L 334: their

- L 337: worse

- L 349: remove the

- L 351: misalignment -> alignment

- L 353: tracks

- L 357: split into

- L 362: depends on

- L 365: relations -> levels

ok for all above. The Tracker mechanical structure have hierarchy, which can be represented as follows: subdetectors(TIB, TOB, TECs), substructures (shells, rods, petals) and individual detector modules.

- L 367: can potentially move for different reasons

- L 369: versus -> and

- L 375: this process can be disrupted

- L 377: can thus result

- L 392: figures

- L 396-397: try to shorten this lengthy reasoning

ok for all above. Modified: Periods with no LAS data are due to either non operational global CMS DAQ or non operational Tracker.

- L 414: that is -> thus

- L 415: during these

- L 421-425: is , was , can , is : tempora inconsistent

ok for all above. Modified: The long periods of data taking are separated by a few technical stops in the year

when the whole of CMS is powered down. During this time the temperature in the Tracker is not well controlled and is close to the ambient temperature in the detector cavern. At the same time some mechanical work and intervention to the CMS detector can take place.

- L 432: as rigid bodies

- L 433: degrees of freedom

ok for all above, modified

J.Cole

* **March 11 2016 v1**

More Hide
Abstract

Line 5: "cosmic rays and collisions".

Line 5: "The laser system monitors the relative movement..."

Line 7: "a few minutes, while the alignment with tracks allows the reconstruction of the absolute positions ..."

Line 9: "During the operating period 2011-2013 the components of the tracker were observed to make movements with a magnitude of around 30 mum."

Line 11: "... that are largely recovered when the temperature is restored to its original value."

OK for above

Introduction

General comment: It is not immediately clear from the paper why you are discussing alignment using particle tracks in this paper, given that we published a large paper on TK alignment a couple of years ago. I assume that what you are including here is something we haven't published before? It might be worth adding something to the introduction to make this more explicit. However, after reading on and reaching section 5, I now assume that you are including this data to provide a comparison with the LAS data - you definitely need to explain clearly in the introduction why the particle track alignment data is included in this paper.

agree

Line 15: "for transverse momenta in the range 1 - 1000 GeV/c."

Line 19: "... delivering a single hit resolution between 15 and 30 mum."

OK for above

Lines 19-21: Why is that the case? How do you arrive at this figure of merit? I see Rainer queried this as well. I think you need to explain (briefly) how this value was arrived at. If it's in the TDR, you could reference that.

I do not really know, asked some people who designed the system... Can be related to the errors in the single hit resolution in discrete detectors. I 'd remove this.

Line 23: Check your temperature units - one of the values you state is missing a "C".

Line 25: "engineering design that tolerates ..."

Lines 25-26: "... and detector displacements. These displacements ..."

Line 26: "... have to be measured and accounted for in the alignment constants ..."

Line 28: "cosmic" -> "cosmic rays"

Line 29: "The actual accuracy of this alignment depends upon"

Line 30: "the number of objects requiring alignment and the size of the track sample."

Lines 34-35: "The movement of the tracker components over much shorter timescales is monitored with the laser alignment system (LAS)."

Lines 37-38: "... better than 5 mum over a time interval ..."

Line 41-42: "Then the measurements of the mechanical stability of ..."

Line 42: "... 2011-2013 and during the LHC long shutdown ..."

Section 2

Line 46: You quote 210m^2 in the abstract. It would be best to keep the numbers consistent.

Line 47: "center" is US English. If you are intending to use UK English it needs to be "centre"

Line 48: "the horizontal x- and the vertical y-coordinates", ie. there should be a hyphen after "x"

Line 49: " ... occupied by the silicon pixel detector, which is operated"

Line 50: "independently of", not "independently from"

Line 52: "The TIB extends in z to +/-70cm ..."

Line 53: "... at each end. The TOB surrounds the TIB+TID. The TOB has an outer radius of 116cm and ranges in z between +/- 118cm, and consists of 6 barrel layers."

Line 56: "along the z-direction, except in the double sided ..."

Line 57: "The strips in the stereo modules are rotated at an angle of 100 mrad, allowing the reconstruction of the z-coordinate."

Line 60: "radial strips. Rights 1, 2 and 5 are also ..."

Line 61: "reconstruction of the r-coordinate."

Line 62: "in more detail."

OK for above

Lines 63-64: Are you saying that the sensors are glued to the readout hybrid or that the sensors are glued together and mounted on the carbon fibre frames? The wording you have used is ambiguous.

everything is glued on carbon fiber independently. will correct this...

Line 72: I'm not sure what you're trying to say by "are inclined with respect to a tangential orientation by 9 - 12 degrees"

see G.Hall remark. Initially it was said: tilted with respect to each other by..."

Line 73: Operation in a high magnetic field ..."

Line 74: "magnetic field causes the deflection of moving charges in the electric field ..."

OK for above

Lines 73-75: Is it really necessary to define the Lorentz shift or can we assume readers already know what this is?

see G.Hall remark.

Lines 77-78: "modules on one cooling loop and each cooling pipe is connected at the edge of the shell to the circular ..."

Line 80: "carried by" -> "supported by"

Line 85: "... openings on the disks ..."

Line 86: I would delete "directions" at the end of the line.

Line 88: What do you mean by "carbon-fiber profiles"?

carbon-fiber structures

Line 96: What does "Only one fixation is precise" mean?

precise in all coordinates, others are quasi-kinematic, with some allowable movements

Line 101: "The overall accuracy of disk assembly ..."

Line 102: "... subdetectors is the Tracker Support Tube (TST). The"

Line 105: Remove the comma after "TECP" - it is not needed.

Line 109: "... thermal screen, apart from the points where the subdetectors are attached to the rails that"

Line 110: "are coming out from the Tracker" -> "leave the Tracker"

Line 111: "... bulkheads, which are also isolated by thermal screens."

Line 113: "the maximum deformation of the TST when supporting the assembled Tracker is about 0.6mm."

Line 113: At the end, delete "Aw"

Line 114: "... inside the TST is of the order of 1mm, but the exact"

Line 117: What is a "quasi-kinematical connection"?

known term in engineering; connection where only some movements are constrained

Line 122: "for the subdetectors are indicated ..."

Line 124: "on one side of the TST."

Lines 125-127: This should all be in the past tense as the Tracker has already been assembled.

Line 130: You can probably delete "to the heating"

Line 132: "cooling plants, each with 40kW of power, are used, each assigned ..."

Line 133: "... distributed amongst the different substructures."

Line 134: Delete "The" at the start of the line

Line 136: "... such that the dew point in the CMS cavern of ..."

Line 139: "... the target operating temperature for the cooling plant was ..."

Line 141: " decreased to -15 degC in order to allow operation with increased fluency."

Line 143: "The actual temperature of the different mechanical structures ..."

Line 145: "Figure 2 shows the temperature measured ..."

Lines 146-147: "... with a target temperature of -5degC, which corresponds to 10-15degC..."

Lines 147-148: "The white area represents non-operational detectors, which comprise about 5% of the total."

Line 151: "Large temperature gradients are observed near readout hybrids ..."

Figure 1 caption: "The red arrows show the connection points and kinematic constraints."

Line 153: "... can be even larger when the temperature is changing."

Line 154: "... electronics rapidly increases the local temperature ..."

Line 157: "before the temperature is stabilized throughout the Tracker volume."

Section 3

Line 161: "... expected in the Tracker determined the concept and components for"

Line 163: "in a high magnetic field ..."

Line 164: "that illuminate the"

Line 165: "...TECS, as shown in Figure 3."

Line 166: "... are injected into the 3 mus orbit gaps ..."

Figure 2 caption: "... and the TEC and TID disks ..."

Line 167: "... collisions. This means that the same detector modules are also"

Line 168: "The 40 laser beams"

Line 170: "... are used to internally align the disks in the TECP and TECM subdetectors."

Line 172: "... axial symmetry the beams are distributed reasonably uniformly in the ..."

OK for above

Line 173: What do you mean by "with Delta phi approx 45deg angular distance"?

8 beams are distributed with axial symmetry

Line 174: Do you mean 6 modules in the TIB and 6 modules in the TOB, ie. 12 in total or 6 modules in both subdetectors combined?

6 modules for each subdetector, i.e. 12 modules in total in the barrel part.

Lines 177-178: It would be best to avoid a one sentence paragraph. Could this be merged with paragraph that immediately follows it?

Lines 180-181: "The attenuation length in silicon is 10cm at 0degC, although it decreases with increasing temperature."

Lines 181-182: "The light output of each laser is regulated by the requirement that the operating current be in the range 0 - 240mA. It is optimised as discussed below."

Line 183: "The lasers' spectral bandwidth"

Line 184: "defines the coherence length, which is relatively small."

Line 185: "interference effects in the optical components and silicon sensors, thus degrading the beam profile."

Line 189: "... is split for use with the different subdetectors (as shown in Figure 3) using beam"

Line 190: You don't need to say "back-to-back" and 180deg - these both mean the same things.

Line 191: "alignment the eight beam splitters for the eight laster beams ..." You've used both "beam splitter" and "beam-splitter". Please pick one that fits with the CMS guidelines and use it consistently throughout the paper.

Figure 3 caption: "Distribution of the laser beams in the CMS Tracker. The eight laser beams inside the alignment tubes are ... The 32 laser beams in the TECs are used ..."

Line 192: "... are located on disk 6 in both TECP and TECM."

Line 193: "... on polarization using a lambda-plate."

Line 197: "... and is completely reflected onto the"

Lines 198-199: "... inclined surface. This procedure results in two parallel back-to-back beams that are both s-polarized."

Line 200: Put commas around "Delta Phi"

Line 200: "For all beam-splitters Delta Phi was measured to be less"

Line 202: "splitting based on a lambda-plate requires depolarization."

Line 207: You've been using "disks" up until now, which I think is more correct that "discs". Please make sure you correct this throughout.

Lines 208-209: "... are integrated into the TOB support wheels."

Line 213: "... the movement can affect the orientation of"

Line 214: "the beam-splitters and therefore the direction of the laser beams."

Line 217: "the TIB to 156 mum in the TEC detector modules.

OK for above

Line 218: "... illuminated from the top of silicon sensors are the standard ones ..." I don't understand what you mean?

from the strips side of the silicon

Line 220: "aluminium coating and is therefore not transparent to the laser light."

Line 221: "coating was removed in a 10mm circular area."

Line 223: "... illuminated by the lasers are also used for particle tracking, their"

Lines 224-225: "The signal from the silicon strips ..."

Lines 227-228: "... is processed further similar to physics data. LAS-specific electronics ..."

Line 232: "... account for the losses in the optical components and ..."

Lines 238-239: "Half of these triggers are used for optimisation of the global alignment, whilst the other hand are used for internal TEC alignment."

Line 243: Do you really mean "compromising" or "comprising"?

compromising

Lines 247-248: "... during technical stops, testing and commissioning no LAS data is collected."

Section 4

Line 253: "... rotate in six degrees of freedom"

Lines 254:255: "... of the sensors can be accounted for by adding another three ..."

Line 256: "... for the LAS and with particle tracks ..."

Line 257: "... and the mechanical stability of the optical components is about ..."

Line 258: "the accuracy of the absolute alignment to ..."

Lines 260-261: " ... LAS measurements allows only the reconstruction of the relative displacement of large structures such as the TOB, TIB and the TECs."

OK for above

Lines 264-265: How does the time interval depend upon statistics? Surely it's the other way round?

Time interval depends upon required statistics. But will remove the time interval...

Line 268: "... can be performed relatively quickly, in steps of just a few minutes."

Line 270: "detail."

Section 4.1

Line 275: "files from the reference values are used to ..."

Line 276: "absolute values."

Line 277: "The second assumption concerns the definition of ..."

Line 278: "... global alignment allow the reconstruction of relative displacements ..."

Lines 279-280: "... while the movement in the z-direction is not constrained in the barrel due to ..."

Line 282: "of the strips in the TECs."

Line 286: "... are small, such that the small angle approximation can be used."

Lines 286-287: "Similarly the 32 internal laser beams in the TECs allow the reconstruction of Delta x ...

Line 289: "Finally, we assume that each laser beam moves as ..."

Line 292: "due to temperature variation in the alignment tube ..."

Line 293: "the LAS alignment procedure the direction of the laser beam is ..."

Line 294: "the offset and the slope ..."

Line 299: "Figure 4 shows beam profiles for the different subdetectors and the two acquisition steps."

Line 308: "... and they are inputs to the chi^2 calculation, where the chi^2 is given by ... in which phi(pbar)"

Figure 4: I think the y-axis labels should be "Amplitude/ADC counts". The x-axis labels should definitely be "Strip number"

Line 309: "... depending on the alignment parameters pbar..."

Line 311: "actual choice of reference values ..."

Line 315: "... rotations of the subdetectors and one"

Line 318: "degrees of freedom"

Line 321: "These features were used to check the stability of ..."

Line 325: "defined by the errors associated with the reconstruction of the laser beam position ..."

OK for above

Line 329: How can you compare uncertainties in microrads and microns? You say the uncertainties in the rotations are slightly worse ...?

angular errors are ~ to errors on offsets/Length, since the typical size of objects 1m, one can compare.

Section 4.2

Line 332: "A detailed description ..."

Line 333: "publications (see [2] and references therein)."

Line 335: "... and the global alignment constants and involves two steps."

Line 341: "for propagation in the field), and n_algnpar the number of ..."

Lines 341-342: "... parameters (for example, there are 5 for the global TIB alignment, similar to the LAS)."

Line 348: "The tracks from collisions were either ..."

Line 350: Note again the US spelling of "center" - use "centre" for UK English, which is what you appear to be using.

Line 351: "run1" -> "Run 1".

Lines 351-352: "For all tracks stringent criteria were applied to the signal-to-noise (> 12), the number of hits (> 7) and the chi^2[2]." Shouldn't you include the requirements placed on the chi^2 in the same way you have for s/n and the number of hits?

Line 353: "The selection of intervals-of-validity (IOVs) that are used ..." I think you need to define a bit better what you mean by an IOV - you need to say that it is a period of running, if nothing else.

OK for above , will remove IOV, confusing in this context.

Line 355: "... of operation conditions, but at the same time should provide sufficient statistics for convergence of the MILLEPEDE ..."

Lines 359-362: Sentence starting "For example the MILLEPEDE configuration" I'm not sure what purpose this sentence serves. Are you just trying to saying that if the MILLEPEDE algorithm were constrained in the same way as the LAS, it would only be possible to achieve the same level of accuracy?

Yes, the MP resolution can be certainly improved by reducing the number of alignable objects, but there are no systematic study on this.

Section 5

Line 364: "... have hierarchical relations, which can be presented as follows: subdetectors ..."

Line 366: "components can be caused to move by different mechanisms and over different time scales."

Lines 366-368: "We distinguish between short-term variations, which occur over an interval of a few hours, versus long-term variations, which occur over a period of a few days."

Line 371: Delete "Then" from the start of the line/sentence.

Line 371: "... TOB this would result in displacements of about 60mum for ..."

Lines 373-374: "... the positions are restored when the temperature is restored to its original value."

Line 374: "However this can be disrupted by the ..."

Line 381: "... are difficlut to simulate in finite element method models"

Section 5.1

Line 388: "The black line shows the evolution of the cooling liquid temperature"

OK for above

Line 389: "... cooling plants. The operating temperature of the cooling plants was kept at" I assume that you mean that the cooling plants were set to run at +4degC?

yes

Line 390: "+4degC throughout the operating period resulting in a temperature of about +6degC in the return pipe."

Line 392: "the switching off of the low and high voltage supplies to the detector modules."

Lines 393-394: "The periods with no LAS data occurred for a variety of different reasons:"

Lines 395-396: "Loss of data resulting from LAS operational problems was below 1%..."

Line 398: "Most of the LAS data was collected during periods of operation ..."

Lines 400-401: Put a "+/-" sign in front of each number

Line 402: "LAS resolution, as shown in the upper right graph in Figure 6."

Line 403: Delete "The" at the start of the line/sentence

Line 403: "interrupted by"

Line 404: "during an interval of just a few hours. All ..."

Line 408: "... of the alignment parameters depend on ... was restarted."

Line 409: "... Figure 6 shows the evolution of the ..."

OK for above

Lines 409-411: "... after a power trip affecting the whole Tracker. Power to the Tracker was restored and the

LAS data acquisition restarted about 30 minutes after the trip." Delete "but before the temperature was fully stabilized that takes about 1 hour" This does not make sense and I do not understand what point you are trying to make.

This is an important point. After temperature variations we assume that the Tracker components moves following the temperature. The temperature evolution depends upon the case of variations and the components material. LAS is operating only when all Tracker is operational, but usually the temperature variations comes with the interruption of acquisition. What we usually see is the residual movements when the DAQ is restarted. Example in the text says that in this particular case the DAQ was started 30 min after the variations, but the temperature stabilization takes about 1h, that is, we see last 30 min movements related to this stabilization.

Line 412: "observed variations of the alignment parameters"

Lines 412-413: "Similar effects can be observed during the power down of the cooling plants;"

Line 414: "mechanical components, as can be see in the bottom right graph in Figure 6."

Line 416: "The long periods of data taking are interrupted by a ..."

Lines 417-418: "After each of these technical stops a new reference ..."

OK for above

Lines 421-422: What does "corresponding to the LAS separation by the reference runs" mean? I don't understand. How do you decide what these nine intervals should be?

This is explained in the Las alignment procedure section. The LAS alignment procedure calculates deviations of laser beam position in each illuminated detector with respect to the reference position. These reference positions can be taken at any time, of stable operation. When there are TS, interventions, etc, a new reference positions are selected because LAS is not running during these periods. On can expect some offsets that can be related to the actual movements but also to some other reasons out of control. For example with one reference taken in 2011 the alignment parameters will jump up to 50 um. So we take a new reference position for each stable period where temp is stable, except short transient periods(eg. power trips of some detectors.)

Line 422: " The MILLEPEDE configuration used for the particle track data was similar to the system configuration for the LAS measurements,"

Line 423: "The errors on the LAS measurements"

Line 425: "Since MILLEPEDE delivers absolute alignment parameters, whilst the LAS measures"

Lines 426-427: "... between the parameters reconstructed with the two different methods are expected."

OK for above

Figure 7: I understand that you don't expect to get the same values from the LAS and MILLEPEDE, but I would expect the offset between the two to remain broadly constant if they were both observing the same displacements. However, when I look at this figure, that is not the case, for example the Rx distribution. What should I conclude from this? Is this indicative of a problem?

The agreement is basically within errors. For some parameters indeed the difference is bigger and can be related to a real displacements that can be reconstructed differently in LAS and MP. Ideally one would intercalibrate LAS and MP (see similar Rainer comment). The thermocycling test is one possibility.

Unfortunately all these studies are extremely difficult. To conclude from the plot, one can only say that variations are within these ~30um for both methods. Actually this drives to the main conclusion of present stud. With good thermal model one can predict all movements. To calibrate the model one would need temperature measurements during forced temperature variations(better using external heaters). To build such a model one need to invest something in soft and the hardware(tempprobes, heaters are not so expansive as eg. LAS).

Section 5.2

Lines 430-431: "... studied during the long shutdown of the LHC that took place during 2013-14. The Tracker ..."

Line 432: " ... +4degC to -10degC and then warmed back up again. The"

Line 433: "evolution of the TIB alignment parameters during ..."

Line 434: "behavior" is US spelling. UK spelling is "behaviour". Please make sure you are consistent in which you choose to use. I've seen some UK and some US spelling.

Lines 435-436: "... activities that prevented the operation of the LAS. For all cool-down ..."

Line 438: "rotates about the y-axis by about ..."

OK for above

Lines 438-439: "20 murad. Warming the Tracker back up to +4degC restores most of these variations..." "with some remaining residual of about 20 mum." 'm not sure what you mean here - do you mean the variation is only partially cancelled out by the increase of the temperature or do you mean something else? Lines 441-442: "The difference between this 0degC and -10degC data is compared with the corresponding LAS measurements in Figure 10."

Yes, there is residual misalignment. Unfortunately the DAQ has stopped we did not see the whole relaxation.

Section 6

Line 447: "... allows the monitoring of the relative movements of large"

Line 449: " During operation at stable temperatures, the long term"

OK for above

Lines 449-450: stability is not "within 30 mum", the movement is, making the Tracker mechanically stable. This sentence needs to be reworded.

During long term operation with a stable temperature the large structures of the Tracker were stable within 30 μm.

Line 451: "in the alignment parameters ..."

Line 452: "... are of the order of ..."

Line 453: "when the temperature is restored to its original value."

Lines 454-455: "The results of this study are important for LHC Run 2, during which the Tracker is being

operated under much colder conditions. The results are similar important for future Tracker upgrades. Laser beams ..."

Line 456: "tool for monitoring the relative displacements of mechanical ..."

During operation with a stable temperature the long term mechani- 450 cal stability of the large structures of the Tracker was within 30 μm.

* **June10 2016 v1**

More Hide
pdf comments

Update notes

TRK-15-002 v0

Jan 20 2016 v0 initial version

TRK-15-002 v1

Feb 21 2016 v1

after first round G.Hall (GH) corrections

All text corrections are included.

TRK-15-002 v2

March 04 2016 v2

after R.Mankel (RM) and J.Cole (JC) comments

all J.Cole text comments are included.

the references are improved (RM)

Brief summary of some additions and clarifications:

* Title: changed (RM)

* Abstract: language corrections (JC)

* 1.Introduction:

-L20-21: alignment accuracy (RM, JC)

-L28-37: added references to CMS align. papers, introduced use of mpede (RM)

-L38-61: introduced laser alignment in ALEPH, DESY, CMS muons. Added about RASNIK as alternatives (RM)

* 3. The Laser Alignment System:

-L203-204: s and p polarization (RM)

-L233-235: antireflex coating (RM)

* 4. Tracker alignment:

-L273-275: Tracker and LAS components movements (RM)

-L278-280: accuracy of track-based alignment (JC)

* 4.1 Alignment with the LAS:

-L305-309: assumptions in LAS procedure (RM)

-L315-323: laser beam profile resolution with LAS (RM)

-Fig. 4: Beam Profiles; labels and tiltles (JC)

-L341-348: LAS resolution (RM)

* 4.2 Alignment with particle tracks:

-L348-361: MILLEPEDE description, small corrections (RM)

* 5 Tracker mechanical stability:

-Fig.6: added comments on plots.(RM)

-L443-452: LAS and mpede long term stability comparison (RM)

* 5.2 Stability during temperature variations:

-L460-461: movements during cycling (RM)

-L465-471: LAS and mpede during cycling (RM)

-Fig.10: temp. labels (RM)

-General: in all plots removed 'preliminary'

TRK-15-002 v3

April 25 2016 v3

after Vidyo meeting 8.04.2016

- removed statements about LAS accuracy in the text , replaced by the stability (RM)

- removed MP errors bars in Fig, 8-10 (RM). This may not be final, waiting results from M.Schroeder, maybe we will get more precise estimate from MP for the large structures fit only.

- added Fig.4 with LAS components (MM)

- add more explanations for the Fig.5, from L394-422

- some minor text corrections in L282-299

TRK-15-002 v4

May 26 2016 v4

after DPG alignment group presentation 18.05.2016

More Hide
Dear Geoff, fellow ARC members, all, >
> *here is my personal summary of the discussion at the TkAl meeting*
> *following Valery's presentation, which can be found under*
>
>
https://indico.cern.ch/event/512682/contributions/2165581/attachments/1274754/1890785/cern18052016.pdf

>
> *- there is clear consensus that the track-based alignment (Millepede)*
> *parameters for large structures cannot be shown with the error bars*
> *reflecting module-alignment precision, as on slides 14-15 of the*
> *presentation and included in the earlier versions of the paper draft*
>
> *- while it would be desirable to compute more appropriate errors, it is*
> *uncertain whether it still can be done with reasonable effort, and in*
> *any case no time scale can be given*
>
> *- it is therefore acceptable to show the track-based alignment*
> *parameters without error bars, as in slides 6-9, under the condition*
> *that no conclusions on precision are drawn or implied that are not*
> *expressly supported by the data. The discussion will focus more on time*
> *granularity / latency. "Disclaimers" concerning what the methods*
> *can/cannot do should be added where necessary.*
>
> *I would like to thank the tracker alignment conveners (Matthias and*
> *Tapio), for dealing with this issue. I CC this message to them in case*
> *they would like to add, modify or clarify anything.*
>
> *Once this point is settled, I expect Valery will inform us ARC members*
> *when all pending points have been addressed, and we can review the next*
> *draft.*
>
> *Best regards*
>
> *Rainer*
>

- modified MPEDE plots Fig 8,9,10, keep only points without errors and the line

- removed MPEDE errors in discussion, subs. 4.2 L353-363

- minor text modifications: L45-50 L59-60

TRK-15-002 v5

June 09 2016 v5

after comments of GH 02062016 and RM 03062016

see the detailed list of all modifications in the above comments.

Majority of suggestions are mplemented.

Added:

- more explanations on the laser coherence length

-more explanations on the LAS DAQ and triggers

-more careful text about the track-based alignment, required statistics, etc

TRK-15-002 v6

June 100 2016 v6

after JC 10062016

CMS Notes

CMS DP-2014/028 -- Movements monitoring of the CMS Tracker detector during the cooling procedure with the Laser Alignment System

CMS DN-2014/004 -- CMS Tracker alignment with LAS during LS1

CMS DN-2011/013 -- Monitoring of CMS Tracker alignment parameters with the Laser Alignment System

-- ValeryZhukov - 18 Aug 2014

- lasresolution.pdf: lasresolution

-- ValeryZhukov - 2016-06-20

This topic: Sandbox > VzTRK15002
Topic revision: r1 - 2016-06-20 - ValeryZhukov