Pixel Luminosity Ring IDR report

→Refresh for Kickoff meeting 31.10.2024

from L.Rossi IDR's report 20.05.2021 – Here a summary

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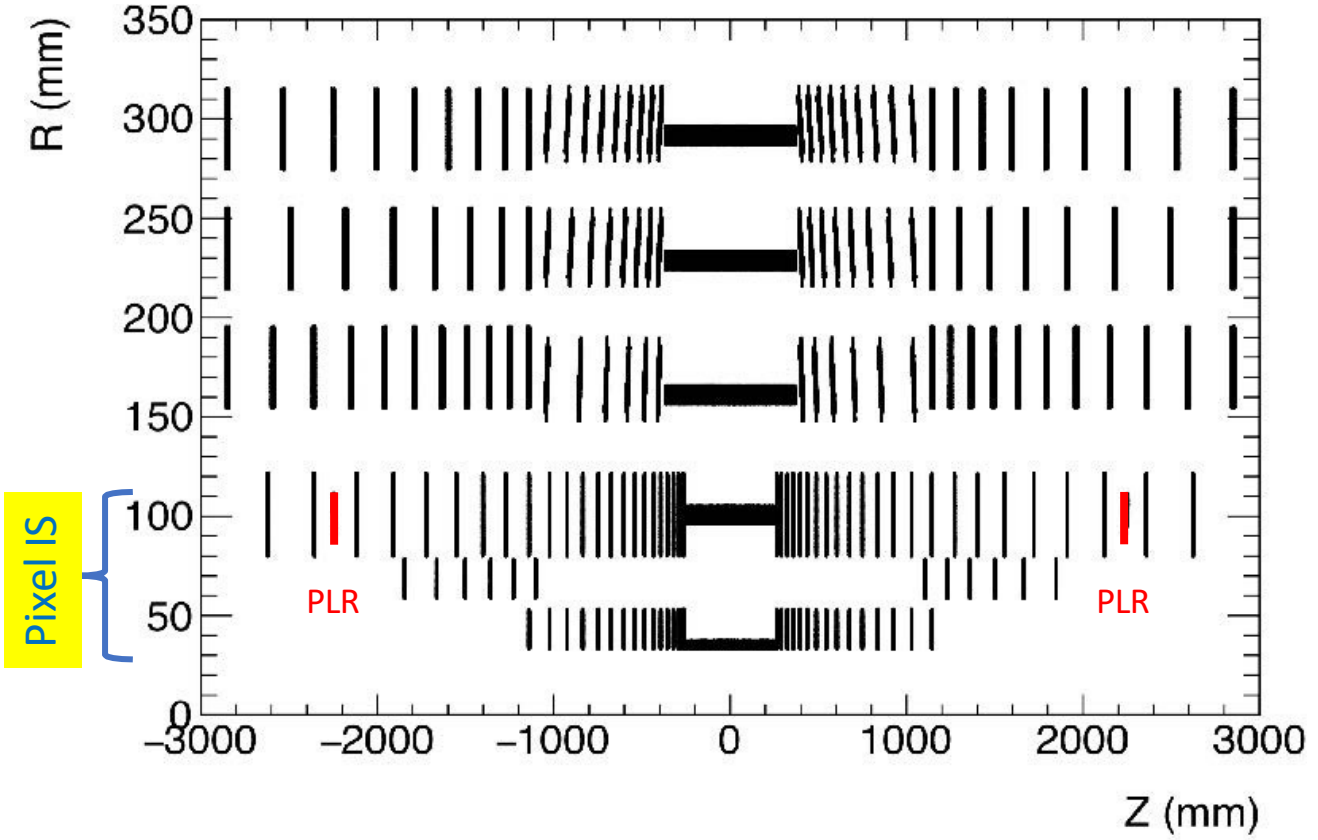
Even if there are still few points to be clarified and followed-up, the review committee thinks that the project is good and solid, considers the IDR passed and look forward to a system Preliminary Design Review once the project will be fully approved by ATLAS and the actions (A1-A6) and recommendations (R1-R6) indicated below will be implemented (see the 10 issues in the next pages)

The plans of the PLR proponents to answer the recommendations and implement the actions are indicated (in blue). The PLR panel finds those plans reasonable.

PLRs must be read out independently of the normal data taking and, when in phase, within the standard data flow.



1) The project assumes that the operating threshold be set at 1ke- and that the module tilt angle is 30^{o}. The average ionization signal left on one pixel is ~4ke- (vs ~12ke- for a 3D pixel module used in the IS). **The small ionization in the PLR determined by the tilt angle is necessary to create the long clusters (size 4&5)** which are important to discriminate between signal (i.e. tracks from collision point) and background (ionization of tracks "flying around"). **These long clusters are "fragile",** under-fluctuation of one pixel may destroy the long cluster reconstruction and create an inefficiency. If this inefficiency fluctuates there will be an effect on the luminosity measurement accuracy. We then recommend (**R1**) to study the effect of long cluster breaking under the following conditions:

a) including the overdrive effect in all simulations (overdrive is the amount of additional charge necessary for the hit to be within the 20 ns window)

b) considering a set of threshold running from 1 ke- to 2ke- (while lab tests indicate that 1ke- threshold should be ok, we cannot exclude that the running conditions will be less favorable. So far there has always been a difference between the threshold that could be used in lab operation and the threshold finally used for the operation in ATLAS)

c) include radiation damage effects up to the expected lifetime dose of 3.5 10^{15}/n_eq.

Please also consider the drift length dependence of the charge collection.

In case cluster breaking is an issue at the end-of-life, a different tilt angle may be considered (still satisfying geometrical and thermal constraints).

R1 Proposal:

a) We will need to continue the program of lab characterization of ITkPix_V1/ITkPixV1.1 to develop improved understanding of the key parameters with bump- bonded sensors (ideally with 3D sensors, but this may start with planar and move to 3D when available). The key parameters are the ones measured using RD53A assemblies and documented in the technical document. They include threshold and noise tuning and performance, noise occupancy performance, timewalk performance, plus TOT tuning and performance. These need further study as a function of threshold and temperature.

b) The lab program needs to be complemented by a testbeam program with hybridized assemblies before and after irradiation to the relevant fluences.

c) In parallel there is an ongoing effort to improve the ITk Pixel digitization code, to include many of the effects above from the lab/testbeam characterization. Finally, more sophisticated digitization codes are available which simulate the behavior of the 3D sensors after irradiation to different fluences.

d) All of these measurements will be made within the ITk Pixel community as part of the ASIC and module qualifications. However, the PLR, with its large angle of incidence, operates in a different regime than any other Pixel modules (50 um path length). Even the L0 Barrel modules, which see a large angle of incidence, have pixels oriented so that the tilt angle is in the 100 µm direction and not the 25 µm direction.

CG: Progress known on two aspects:

- Data taken at 30 degrees inclination 3D FBK 25x100 irradiated EOL in sep 2023.
- Improved ITk Pixel digitazation code, see just published 3D pixel paper, G. Aad *et al* 2024 *JINST* **19** P10008

2) **Simulation on radiation damage** of 3D 25X100μm^2 sensor exists and should be used. We recommend (**R2**) to collect experimental data on radiation damage of 3D 25x100μm^2 to verify the simulation results and to be preferentially used for the studies at 1c.

R2 Proposal:

a) We do plan to investigate these new digitization models, which are starting to be compared to the IBL/FE-I4 3D modules at the end of the IBL. Unfortunately, in the IBL, the 3D modules are at the extreme end of the tracking acceptance, so one needs to use tracks with extreme z0 values in order to have them pass through enough Pixel modules to do useful tracking studies, so the statistics are low.

b) We have tried to collect the relevant Pixel data on irradiated 3D sensors, but most investigations only looked at the efficiency (which is excellent in the PLR region, as discussed in the technical document), New dedicated measurements need to be made at larger angles of incidence. Unfortunately, the ITkPixV1, with its flawed TOT memories which need to be constantly refreshed to control their power consumption, cannot easily be operated in the asynchronous test beam environment. The power consumption issues are solved in ITkPixV1,1, but at the cost of having a binary readout. Without the charge measurements, it is harder to assess the available headroom after irradiation. The PTOT circuitry can also be useful but has ambiguities due to the HitOR readout that make it difficult to analyze clusters larger than 1x4 pixels.

c) Again, all of these measurements will be high priority for the ITk Pixel community to perform in 2021 and 2022.

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3) The TDAQ system has been designed using the Run3 architecture. It has to be redesigned (**A1**) in such a way to meet the Run4 specifications (note that the FELIX maximum speed rate (currently 1 MHz) needs further discussions). The PLR group is strongly encouraged (**R3**) to **work out the conceptual design together with the TDAQ system in terms of readout** (FELIX), dataflow and trigger (LTI) to understand the implication to support the >1 MHz rate and the opportunistic read- out. The opportunistic read-out is of paramount importance to correct for detector parameter drifts, so this needs special attention.

A1 & R3 Proposal:

a) We will discuss with the relevant TDAQ experts a design suitable for the Phase II architecture, and re-evaluate the hardware needs.

b) The unpacking, clustering, and counting code will be moved to an EventFilter-like node that actually should make the design easier. One key challenge here is scheduling PLR events into the EF-like nodes at 1 MHz. This will be discussed with the EF experts. Overall, however, this scheme should be similar to other detector calibration streams (like the Muon calibration stream) so we will explore whether we can profit from common infrastructure.

c) Designing a scheme with the LTI to be able to read out PLR data with a normal ATLAS L0A is a key to monitoring PLR cluster efficiency by matching with ITk forward tracks. We will work with the LTI experts (Thilo) to understand how this can be accomplished.

d) While we don't strictly need trigger rates > 1 MHz, this will be highly desirable for lower- luminosity operations (such as vdM scans). We will pursue this with the FELIX experts to understand just how difficult supporting faster readout (particularly at smaller event sizes) might be to implement.

4) The **mechanical stability requirements** are probably easy to be satisfied. They are nevertheless missing and need to be defined (**A2**) (together with the indication of their effect on the luminosity measurement, if any). The same is true for the alignment requirements, which also need to be defined (**A2**).

A2 Proposal:

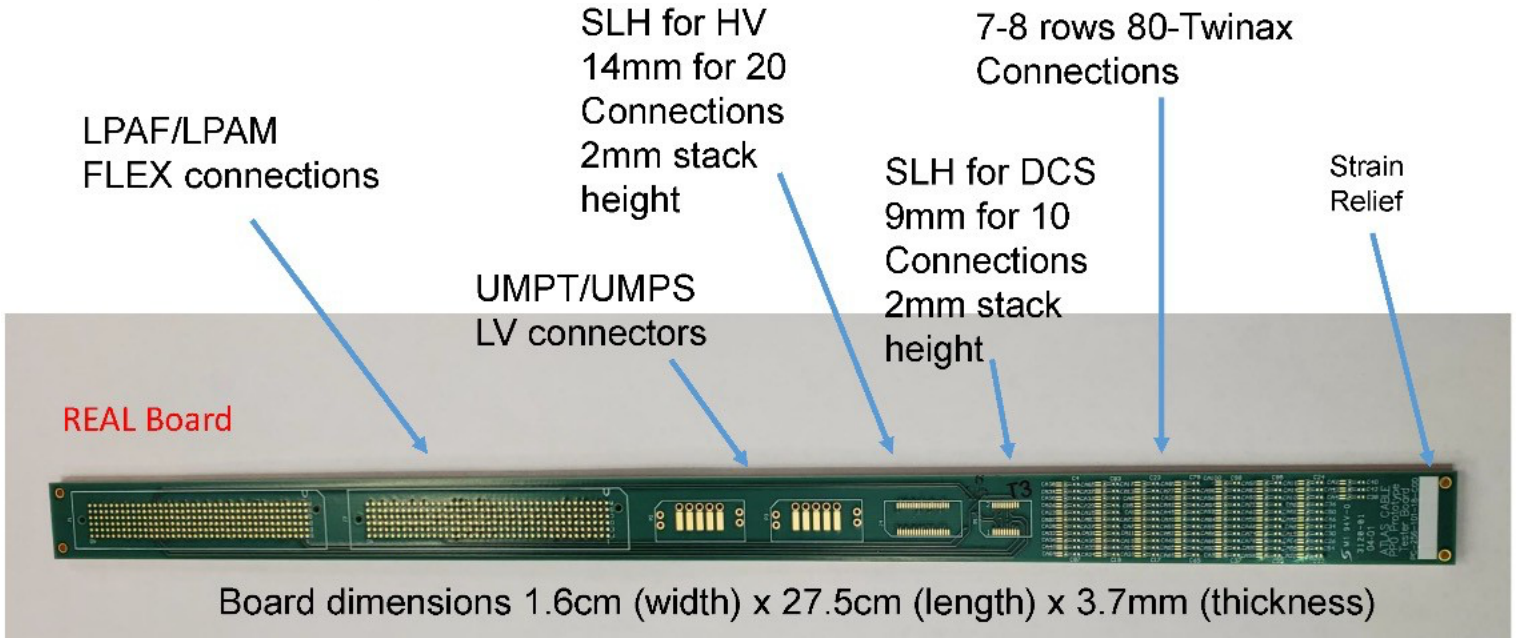
a) It has been proposed that the PLR participates in relevant reviews for the ITk Pixel tracker where possible. The next such key review would be the Local Supports FDR, which is supposed to happen in Oct 21. We will investigate whether on this timescale the necessary material for a combined Spec Review and PDR could be prepared for the PLR. One challenge will be that the project will not yet be formally approved by ATLAS on this timescale, and hence we will not be able to significantly engage engineering and technician person-power for such reviews. This will be explored within the relevant institutes. It might be necessary to further delay the PLR review, but this carries the risk that inconsistencies could be frozen into the PLR designs if they are not reviewed together with the ITk Pixel designs.

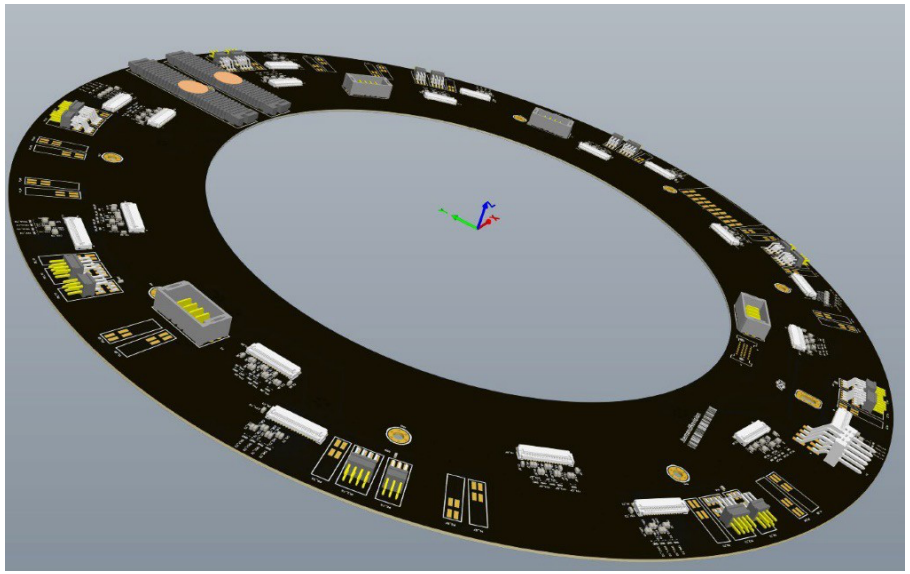
5) **Module loading accuracy** has to be specified too (**A3**) (this is important for no-stress pigtail placement)

A3 Proposal:

a) Such questions should be addressed at the same time as the A2 proposal above.

6) The CORE cost of the project is **adequate with the exception of the WBS 2.4.7.2** (local services) where the scaled cost from the IS corresponding table indicates a large over-cost for the local services. This seems to be related to the added complexity **of having 4-data link** per chip which demands a complete redesign of the printed boards and therefore a large NRE cost. We recommend (**R4**) to make a comparison of the 3-data link cost and the 4-data link cost and also evaluate the effect of the 3-data link choice on the luminosity accuracy measurement (or the risk this may bring in).



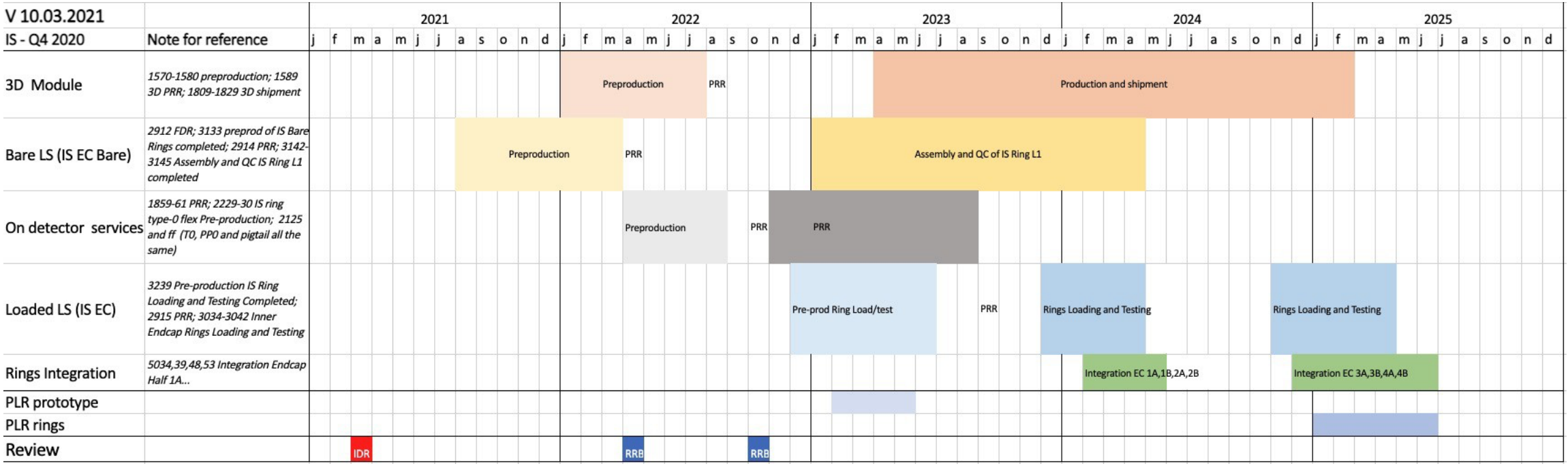


CG: I think it has been descoped to 3-data link and agreed to use the Pixel PP0 so to minimize effort .

R4 Proposal:
The PLR community would like to postpone this decision until the designs for the on-detector services for the Pixel Inner System are more mature. We also agree that at the present time, the trade-offs between cost/complexity and performance appear to suggest that the 3-links/ASIC option would be the best choice. However, at the present time, the designs for the Ring PCB and the PP0 are still at an early stage. In recent discussions, the option of making the Intermediate Ring PCB compatible between the Intermediate Ring and the PLR (using two Ring PCBs, for the PLR as the Coupled Ring does) could provide an option which would require very little incremental work. Since this decision does not need to be made now, we prefer to wait until the on-detector service designs for the other rings are more mature and make a decision with more detailed knowledge. We realize that this is quite likely to remain the 3-link option but would prefer to have the extra bandwidth contingency if it is relatively straightforward. This would allow operation over a wider range of conditions (lower thresholds and higher background hit rates), and the lower link occupancy may lead to important improvements in deadtime-related data losses (something that the redundancy of the pixel tracker can afford, but we prefer to minimize).

CG: I think it has been descoped to 3-data link and agreed to use the Pixel PP0 so to minimize effort .

7) the schedule implies that the PLR is a "follow-up" of the IS project. The milestones specific to the PLR project can be met if CORE resources start to be available in 2022. The project relies heavily on what they refer to as "deliverables" by other groups and people. This needs to be formalized (**A4**) on due time, putting in writing who commits to deliver the parts of the PLR (or enlarging the PLR group to include all those providing the needed "deliverables").



CG: Hopefully addressed by the kick-off

A4 Proposal:

a) Working closely with the ITk PL, the Pixel PL, and the Inner System management, this work has been started. It will be necessary to prepare the ATLAS MoU and associated CORE costs for the EU and US deliverables, as well as the US ATLAS RLS/Budget for the US deliverables. The present status of this work is covered in the UCG-oriented PLR Management document that accompanied the technical Project Description document. We will continue the collaborative effort on this work and hope that we can manage to put together a package of support that would allow the construction of this interesting luminometer for HL-LHC.

8) The technical and engineering resources needed for the project are shared with the ITk Pixel project (mostly IS). More detailed commitments are impossible at this stage, but they must be prepared (**A5**) before the PLR approval in ATLAS.

A5 Proposal:

a) We agree, and the expectation is that the technical and engineering resources will come mostly from the US ATLAS Pixel Inner System team. However, if this does not prove to be possible, we will explore other options in Europe. This action is tightly coupled with the A4 action above.

CG: Hopefully addressed by the kick-off

9) We recommend (**R5**) to explore the possibility of adopting an additional luminosity measurement method based on "event-counting" (event = a crossing with at least a certain number of clusters of a minimum cluster-size) or on "hit-counting" (hit = a cluster of a given minimum size). The study should evaluate if there is any cross-check capability useful for the main PCC algorithm or any advantage, in particular for the measurement of tails in the Van der Meer scans.

R5 Proposal:

a) We agree and will pursue studies to assess the comparative stability of event counting vs. pixel cluster counting at high and low luminosity. Event counting will be much easier to implement in the Phase-II readout scheme, as all the data from a single event will be present in a single processing thread, so the technical issues are no longer significant. At low luminosity, event counting will provide some amount of statistical gain, so that alone may be worth the small effort to implement this capability.

10) In various places the project document refers to "pre-production" when from the context (i.e. from what those devices are for) it is clear they are "prototypes" instead. One uses a prototype to verify a design and check that the device does the job. One uses a pre-production device to verify the vendor can produce what one has asked them to produce. This choice was justified in the discussion as it makes the fund rising easier. We believe this needs to be corrected (**A6**) because it is very confusing wording and may impact the CORE cost. In general, the structure of the project (heavily based on IS resources) and the prototype vs pre-production issue require a suite of technical reviews which would not be the usual one. We recommend (**R6**) that this issue is discussed and agreed with the Upgrade Management.

A6 Proposal:
This is an important point. The present plan for producing the “pre-production local support” is intended to produce a CORE item after appropriate reviews. The PLR local support is a modest extension of the Quad Ring local support, and we believe that a pre- production quality part can be produced without an intermediate prototype. For the on-detector services, the situation is more complex, and this most likely will require prototypes to be manufactured.

CG: Prototype vs preproduction on such a small project to be clarified in the MoU

Depending on how the designs evolve (e.g. towards a common design for the Intermediate Rings and the PLR), the prototypes and perhaps even pre-production costs could be negotiated with the Pixel Inner System project.

In general, we do not anticipate that the PLR project will have access to dedicated R&D funds to develop prototypes.

We agree that a determination of what the appropriate level of project oversight will be (e.g. technical reviews, schedule reviews), with the likely inclusion of a basic UCG-like review of resources, and establishment of institutional commitments within the project, are all likely to be important components of a successful project.

R6 Proposal:

a) We will discuss with Upgrade management about the best way to proceed, and what language and review organization is appropriate to use here. We certainly want to avoid any unnecessary or extra reviews.