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PDR of Non-invasive profile monitor (NPM)

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Comments to PDR for NPM design for ESS
Date of review Meeting: January 31st, 2017

General

- This is a very challenging project.
- The subject was presented in a very good and appropriate manner.
- Very nice simulation work indicates that the from a fundamental physics point of view, an IPM can work in the cold LINAC, since
  - Sufficient signal expected
  - Acceptable field uniformity can be achieved within the space available
  - Space charge effects are small, at least for ion collection, at a field strength that appears achievable.
- The prototyping plan for the readout is very ambitious and diverse. To meet the schedule constraints, it should be focused down to fewer options, and the tests tailored to address the most critical questions.
- In order to have a detailed design ready by the CDR, the choice of readout technology needs to be made well ahead of the CDR.

Scope for profile non-destructive profile:

Observation: The scope of the CEA project is to provide 5 dual plane IPMs (so 10 single units in total); i.e. one dual plane IPM for Spoke section, three for medium beta and one for high beta.

Comment: The currently foreseen delivery of the cold NPMs is scheduled after the planned installation of the LWU hosting the spoke NPM.

Recommendation**:** The delivery plan should be aligned with the installation schedule. If delivery cannot be done by the time the LWU needs to be installed, additional resources in terms of time and manpower for later installation needs to be identified.

General requirements for the NPM:

Observation: Level 4 requirements were presented and a clarification of requirements hierarchy was offered in response to questions. There is a relation between wire scanner and NPM requirements, since both are needed to fulfill the full range of Level 4 requirements.

Comment: A detailed list of Level 5 requirements for the cold LINAC NPM was not presented. Some requirements appear to be only verbally agreed on.

Recommendation**:** It is recommended to document the Level 5 requirements and system performance specifications to communicate it in more details to achieve the expected performance and operating conditions. This is needed to manage expectations of the stakeholders, primarily commissioners and operators.

Signal estimation:

Observation: The count rate for different currents and pulse lengths had been estimated for the interesting range of beam energies. The rate is sufficient for a profile measurement within one pulse by an IPM.

Comment: The rate estimation is trustful. One minor comment: The usage of W-values might not be completely valid, a somehow higher value for the energy loss conversion to the number of residual gas ion-electron pair for a single collision might be used e.g. about 100 eV, but this doesn't change the overall results.
Recommendation: The IPM seems is an appropriate choice.

Background estimation:
Observation: Using any particle detector, the background created by lost protons might be a challenge.
Comment: No background estimations were given in terms of count rate of the different possible detectors assuming realistic beam loss estimations. Electromagnetic interference also needs to be considered, in particular for the strip readout option.
Recommendation: The background must be evaluated either by simulations or by experimental investigations. One possible location might be SNS or CERN LINAC4, where such system (small vacuum vessel with the detector inside) could be placed closed to the beam line. However, such measurement requires quite some investment of man-power.

Space charge simulation:
Observation: The effect of the space charge influence was modelled in detail and are convincing. For typical beam parameter the ion detection mode leads to an acceptable profile reproduction.
Comment: The simulation seems to be completed. The reason for the choice of box-car distribution in the longitudinal direction was not clear to the committee, but it does not appear to have a significant influence on the results.
Recommendation: Only the ion detection scheme should be considered in future and the IPM should be optimized for this purpose. Electron detection is more difficult, because such slow electrons are influenced by any external magnetic field e.g. from quadrupoles, ion pumps or vacuum gauges. Moreover, the secondary electrons liberated from the residual gas ions hitting the negative HV electrode must be suppressed efficiently.

Space charge simulation influence on HV:
Observation: The space charge influence was modelled for different electric field strength.
Comment: The profile broadening between an applied voltage of 30 or 60 kV seems to be minor. However, the mechanical design for 30 and 60 kV could be significantly different.
Note that the use of an optical readout would permit the use of a symmetric voltage (e.g. +/- 15kV)
Recommendation: The requirement of using 60 kV for the field cage should critically reviewed and only the required value of the HV should be chosen.

E-field cage:
Observation: The electric field of the cage was simulated in some details and characterized by the 'E-field-fluctuations' within a disk of a variable radius. In conclusion a quite simple design was chosen without a 'wire' and ground plate between both IPMs.
Comment: The characterization by the 'E-field-fluctuations' was discussed. The plots don't specify the longitudinal position (z-direction) of the evaluation disk and therefore it might be invalid. A criterion for the required field quality was not discussed (which is regarded as a difficult task anyhow).

An engineering design of the high voltage field is not yet available.
Recommendation: The evaluation of the field quality should be performed for different longitudinal positions. This is should lead to the statement of an adequate longitudinal extension of the detector i.e. the size of the MCP.
The final field configuration should be verified by tracking test particles, preferably in an existing software such as COMSOL.
The engineering design should be started soon taking the simulation results into account this might lead to some simplification of the cage design (e.g. in the number of degraders)
Possible interference between the IPM and the Wire scanner measurements should be investigated.. If the high voltage cannot remain during wire scans, the impact of this on the operation of the devices should be assessed. Preferably, the systems should be fully independent. Independently of this, the issue of trajectory correction for the e-field effect needs to be addressed.

Mechanical design:
Observation: The vacuum vessel seems not to be optimal for the IPM insertion. A detailed mechanical design was not presented taking HV up to 60 kV into account. The design of the LWU vacuum chamber was frozen shortly after the kick off meeting for cold LINAC NPM, and a modification request could not be accommodated. This may limit the maximum possible drift field that can be used.
Comment: Due to the high voltages, the mechanical design must be done with some care; sufficient space must be foreseen on the flange for the HV feedthroughs. In case strip readout such feedthrough must be placed on the same flange, in case of phosphor readout the viewport could be installed opposite to the flange holding the field cage.
Recommendation: The mechanical design should be started soon to leave sufficient time for possible improvements in case of any sparking. A vacuum vessel optimized for an IPM would be an advantage (only 5 out of more than 60 vessels have to be modified).

Vacuum issues:
Observation: Four different designs were presented. From a vacuum technology point of view, these designs have different level of complexity none of which, however, looked extremely challenging or unrealistic.
Comment: The vacuum group will offer guidance in the selections of materials and manufacturing technologies. In case of necessity, a vacuum outgassing measurement chamber will be available for the determination of outgassing rate of components deviating from a strict vacuum etiquette. Some specific components (e.g. Resistors, MCP) have already been cleared by the vacuum group.
A mechanical design that minimizes complexity in the vacuum domain is considered beneficial to the ESS installation timeline as well as to the initial debugging of the NPM hardware.
Recommendation: A RAMI / FMEA analysis is recommended in order to categorize the designs and to select the best promising solution. A preliminary test campaign on a machine / set up with vacuum conditions closer to the ESS requirements is recommended.

Read-out detector technology general comment:
Observation: Several systems were proposed: Strip readout with an integrator via the CARAMEL board, phosphor screen each with and without MCP, TimePix3 readout.

Comment: Due to the tight time schedule not all alternatives can be tested in detail and a choice has to be made now. The TimePix3 is a novel technology for IPMs but further tests seems to be required and might not be feasible within the give time frame. In particular, the ion readout must be investigated with tests e.g. at an ion implanter; at CERN-IPM ion detection seems not be possible. (It should be investigated whether the silicon detector might be modified by the implantation of the residual gas ions.)
Recommendation**:** We propose to take the MCP based detector as the baseline design. The phosphor readout seems to be technically simpler because commercial MCP phosphor combinations are available. A camera reading should be a standard for the ICS. Investigations with the TimePix3 technology should be performed with lower priority (but are still interesting from a scientific point-of-view).

Detector technology MCP requirement:
Observation: For the strip and phosphor readout a design with and without a MCP was discussed.
Comment: To get an overlap with the wire-scanner, a low detection threshold must be foreseen using an MCP.
Recommendation: It is recommended to have a design with an MCP to get sufficient signal for low current or short pulse operation. Usage of a single MCP might be possible which enable better spatial resolution and less risk of false profile reproduction due to saturation. Further studies are required including a discussion with the MCP suppliers (Hamamatsu or Photonis).

Detector technology MCP saturation:
Observation: Possible saturation effects i.e. count-rate dependent decrease of amplification were discussed briefly.
Comment: Saturation might lead to a wrong profile reproduction which is difficult to detect during operation.
Recommendation: This saturation effects should be discussed with the suppliers (Hamamatsu or Photonis).

Efficiency of MCP:
Observation: An estimation of the MCP efficiency was give: For 20 % efficiency decrease a duration of 14 years of continuous operation was estimated. A calibration method by UV lamp is foreseen.
Comment: According to some persons' experience, this duration of 14 years seems to be unrealistic long. GSI has good experience with a Deuterium UV lamp emitting light down to 200 nm; a MgF_2 vacuum viewport is required to transfer this short wavelength to the MCP. For this wavelength optical fibers might be difficult to use. Tests at GSI with light sources of longer wavelength failed for the used Photonis MCPs; more details can be communicated on request.
Recommendation: The expected efficiency decrease of the MCP should be evaluated again taking the beam profile into account. Permanent profile monitoring should not be foreseen i.e. the MCP voltage should be lowered to prevent amplification in case the beam profile is not recorded.

Comparison strip versus phosphor readout:

Observation: The pros and cons of strip versus phosphor readout were only addressed briefly.
Comment: Generally, the strip readout could be done within a more compact installation, but low current measurements could be influenced by EMI problems. The pre-amplifiers must be installed quite close to the beam line to avoid large capacitance related noise contributions to the signal path. A phosphor readout is more robust in terms of EMI but the camera might suffer significantly from radiation damage. Radiation hard cameras are available but some are quite expensive (e.g. from Thermo-Fisher). Moreover, due to the 2-dim image as yielded by a camera readout, a better background recognition might be possible.
Recommendation: The choice between both types is not easy and requires some more study; presently the phosphor readout seems to be simpler.

Beam based tests:
Observation: Tests of the NPM are proposed at IPHI and possibly at COSY.
Comment: A tests at IPHI is preferred over COSY because beam parameters are more similar to ESS in terms of beam current, pulse length and beam profile. Only the energy is much lower and background issues could not be tested at IPHI. Moreover, the CEA team might have a better access to IPHI than COSY.
Recommendation: The tests at IPHI should have higher priority than at COSY. There may be even more suitable locations for some tests, in particular for background considerations at, e.g. at CERN LINAC4 or SNS.

Cables:
Observation: Depending on the chosen read-out method, different cables are needed.
Comment: There appear to be a mismatch in time schedule, since the cables need to be specified before the readout is determined. At least some cable can be specified independent of readout system.
Recommendation: Avoid as much as possible to defer cables choices. Reducing the readout options early will help in this regard.

Controls:
Observation: Extensive evaluation of the four possible solutions is planned to be done in about one year. Technically all solutions seem to match to ESS/ICS selections so they are all doable, but with significant differences with respect to the required efforts. Details concerning data acquisition, handling of data, storage, online calculations et cetera were not discussed. This may be too early for time being, but must be initialized significantly prior to the installation.
Comment: Systems like this will require significant beam studies that collect large, correlated data sets. ICS and BP should anticipate this and prepare tools (well beyond the configuration of the current archiver appliance) that support these studies.
Recommendation: -Clarifications about the final (controls) integration work should be done as soon as there is one preferred solution selected. List pros and cons of evaluated solutions, considering all relevant aspects (quality of measurements, implementation effort, future development). If the most work-intensive solution turns out to be superior to others, consider relaxing the timetable slightly (note: having said that, it should be ESS/BI and or BP to decide how soon you really need the NPMs).

Quality assurance:
Observation: Quality and verification was not discussed much in review.
Comment: A strategy for the prototype down selection was presented.
Recommendation: A verification plan that includes inspections and tests for production, and a plan for factory and site acceptance testing, should be presented at the CDR.

Answers to charge Questions:

1. Are the operations and commissioning performance requirements for this system well understood and properly documented? Is the scope of the system well defined? ***Generally yes. Level 4 requirements are specified, although some Level 5 requirements need to be documented.***

2. Are all interfaces properly understood and documented? In particular
   a. Is the interface with ICS well understood and functionality well covered? Is the control integration of the system properly addressed? ***For the stage of the project yes. Interfaces depend of the readout option, and should be further defined in the near future.***
   b. Is the interface with the LWU (e.g. vacuum, mechanical, electrical) well understood and documented? ***Yes (see comments).***

3. Is the conceptual design likely to fulfil all requirements and respect all interfaces, and is it mature enough to begin detailed design? Have alternate design options been properly considered? ***Simulations have shown that IPM is an appropriate choice. Alternative options have been considered. The detector technology needs to be specified early in the detailed design process to meet the schedule.***

4. Is the planning appropriate and consistent with the work unit scope and overall ESS plans and milestones? Are the key interface milestones (e.g. installation) identified in the planning? ***An intermediate milestone concerning the readout technology may be needed. Also, currently NPM development and production planning is not fully consistent with the installation planning.***

5. Is there an acquisition strategy for major procurements appropriate for this design stage? In particular, is the lead time for procurements and contracts properly accounted for in the planning? ***Yes. Issues are not foreseen due to the small scale of procurement.***

6. Is the verification strategy appropriate for this stage of the project? ***Yes, this will need to be more detailed later.***

7. Have RAMI aspects been considered in the design choices at a level appropriate for this stage of design? ***Yes. RAMI aspects has been considered in the work so far, and needs to be part of the down selection process.***

8. Have the project risks and opportunities been properly identified and their impact considered in the conceptual design? If required, is there a mitigation plan? *Yes.*

9. Have potential safety hazards been properly identified and considered in the design choices? If required, is there a mitigation plan? ***At this stage, no major safety hazard foreseen. 60kV will require some care.***

10. Were any other issues identified during the review? ***See comments.***