TDIS general design internal review

CERN

1 December 2016

Review Panel Report

15 December 2016

Table of contents

LHC TDIS general design internal review

1 Review objectives and Review Panel

The TDIS (Target Dump for Injection Segmented) for LHC review was held on 1 December 2016 at CERN.

In view of the installation of a new generation of TDI during LS2 the general design and concept has been reviewed before proceeding to the detailed drawings for the manufacturing of a prototype of the system.

The objectives of the review are:

- Validate the technical choices made for the design of the new TDIS in terms of general mechanical/thermal concept, reliability of alignment and control for machine operation, exchange in case of failure.
- Discuss the design by taking into account the past experience of operation with the previous generation of TDI and confirm that the new design addresses the limitations encountered in the past.
- Identify possible limitations and critical items in the current design in terms of robustness with respect to thermo-mechanical efforts, compatibility with machine vacuum, compatibility with impedance requirements and beam quality, possible occurrence of high order RF modes (HOM), possible occurrence of electron cloud.
- Propose the tests to be made on the prototype to validate the design before series production

Membership of the Review Panel and specific expertise is as hereafter:

- Mauro Taborelli, chair (TE-VSC) – e-cloud, thin films, vacuum
- Alessandro Dallocchio (EN-MME) – materials, manufacturing, thermo-mechanical calculations
- Alexej Grudiev (BE-RF) – impedance, beam dynamics, operation
- Verena Kain (BE-OP) – collimation, beam dynamics, machine protection, operation
- Stefano Sgobba (EN-MME) – materials, assembly technology, metrology, corrosion

The agenda of the review is given in appendix 5.1

2 Charge to the Panel, content and preparation of this report

2.1 Charge to the Panel

The charge to the Panel is under the form of questions to be addressed by the reviewers:

- **Does the present design address the issues encountered during operation of the previous generations of TDI?** (Added by the reviewers) The experience gained with the operation of the previous generations of TDI should be used to avoid known problems.
- **Low-Z absorber materials:**

  - Do the reviewers support the presented strategy regarding the material selection for low-Z jaws (i.e. graphite to be used unless proven to be non-suited by HRMT-28)?
- **Impedance/vacuum:**
  - Are all the taken measures (improved cooling, RF fingers, vacuum pumps etc.) sufficient to avoid issues like we had with the present TDIs? Do we need a tapering?
  - What is the maximum value of impedance acceptable for the jaws? Is the strategy of non-coated low-Z absorber blocks supported? (note: in case of grazing impact, significant damage of coating is likely to happen).
- **E-cloud:**
  - Is e-cloud an issue?
  - Is a low-SEY coating needed?
- **Instrumentation/interlocks**
  - In terms of gap measurements (in particular for the BETS), is the proposed instrumentation layout enough (using redundant anti-collision LVDTs like on the collimators)?
  - Is more instrumentation needed to make sure that the jaws of the three modules are well aligned with each other?
  - Which measures could be taken to improve the reading accuracy from the temperature sensors? How could EM coupling with the beams be avoided?
- **General:**
  - Is any important aspect neglected in the design?
  - Apart from the usual mechanical and instrumentation tests foreseen on the prototype, are there any other tests that could be performed?

2.2 Content and preparation of this report

The objectives of the review have been given in section 1 of this report and the charge to the Panel in section 2.1.

In order to provide specific and detailed replies, the Panel has broken down the subject into following main topics:

1. Lessons learned from the operation of the previous generations of TDI and comparison with the present design
2. The choice of the materials, heating and beam impact effect (mechanical and thermomechanical stability)
3. Impedance (RF fingers, tapering, jaws surface conductivity)
4. Electron cloud
5. Control: jaws position/alignment, interlocks, temperature measurements
6. Recommended tests on the prototype
7. Other issues

The Panel reply is based on the above breakdown of topics and given in section 3 of this report.

The final review is based on the presentations of 1 December 2016. The final version of the report is approved by Panel members on 15/12/2016 and made available shortly after.

3 Panel reply

In the following sections, replies and recommendations of the Panel are *in italics*.

3.1 Lessons learned from the operation of the previous generation of TDI

The TDI devices at Pt2 and Pt8 were modified in two previous stages and several limitations were identified along their lifetime. It should be noted that the present TDI has been operated mainly with trains of 96 bunches at 25 ns spacing from the SPS, which is less than the nominal 288 bunches per train (this was due to issues in the internal dump of SPS and not to the TDI itself), and with 1.2 x 10^{11} p/bunch to be compared with 2.3 x 10^{11} p/bunch in HL-LHC.

Thermo-mechanical stability, overheating:

RF heating, possible heating from HOM and/or electron-cloud and the resulting effects on vacuum and LVDT drifts are the main operational issues associated with the current TDIs.

The previous generations of TDI were all based on a single long tank hosting full-length jaws (about 4 m). The long jaws exhibited some sag, which significantly reduced the possible accuracy of the alignment as well as the reliability of the LVDT measurements

This effect is addressed and highly improved by the TDIS segmented design with shorter (about 1.5 m) and stiffer jaws. The segmented design adds the complication of aligning the 3 tanks on the girder, but this operation is made on surface during assembly and the stiffness of the design is expected to guarantee the stability. (See 3.5 for more details on TDIS alignment and possible drawbacks).

In the first TDI generation (before LS1), RF induced overheating provoked an irregular deformation of the jaws, reducing further the alignment accuracy. In addition the heating produced a thermal drift along fills. The RF heating was due to the failure of coated BN blocks and the absence of cooling. The deformation was favored by the long jaws.

The replacement of BN with graphite blocks already in the present TDI has reduced the vacuum and background effects (see 3.2 for materials choice and 3.3 for the RF heating). In addition the new TDIS will have a much shorter and stiffer jaws with improved cooling (contact of the cooling pipes close to the blocks and done with much higher pressure on their support).

Vacuum issues

The TDI in 2011 exhibited a slight pressure increase, which can be related to thermal outgassing along the fill. This is similar for both positions, Pt2 and Pt8. No issues from this point of view are reported by the ALICE experiment, for the present TDI with copper coated graphite blocks.

The new TDIS has a significantly larger pumping speed and larger capacity of the NEG pumps. It has also an improved cooling (contact of the cooling pipes close to the blocks and done with much higher pressure, in the present TDI the contact is with the envelope only).

Random pressure spikes all along the fill were present on TDI at Pt8 in 2015 and provoked eventually beam dump: this phenomenon did not show conditioning. In addition some spurious spikes with retracted TDI were also observed.

This effect occurred on the initial version with BN blocks and has been eliminated by the replacement of BN with graphite blocks.

In the current TDI, pressure spikes were only detected when opening the jaws in presence of the beam and this is difficult to explain by thermal effects. The spike was just present in the TDI equipped with titanium plated aluminum frames (Pt8) supporting the jaws (the other in Pt2 has copper coated aluminum alloy frames) and appeared for the first time with the beams of the scrubbing run 2016. The spike is not present when moving the TDI without beam and seems to decrease in intensity along operation.

There is at the moment no sound explanation of this effect. The observations are compatible with the occurrence of electron cloud for a specific position of the jaws. ***The panel recommends to simulate the behavior of the presently installed TDI*** *with respect to e-cloud and to compare it with simulation performed for the TDIS in order to explain the observations and be sure that the same will not occur in the new setup.*

Alignment problems

The beam based alignment of the present TDI is complex and tedious and the accuracy which is reached is limited (+/- 50 μm and some 100 μrad misalignment given by the measurement step-size). Part of the problem is due to the fact that with current design an absolute calibration of the LVDTs is not possible and therefore the operation cannot rely on the mechanical gauges only. Thermal drift further reduces the accuracy. The largest contribution to deformations is the beam induced heating. The deformations were never accurately measured, but are considered as fully reversible (see also § 3.5 for the envisaged eventual measurement techniques). The protection given by the TDI jaws was seemingly never compromised.

The much stiffer design of the new TDIS with shorter jaws and LHC collimator-like design of the actuation system leads to an improvement of the accuracy and stability. Upper and lower jaws will be calibrated to the same center positions to reduce the complexity of the setting up. Thermomechanical stability is increased by the improved cooling. The angular alignment is no longer considered as necessary with the shorter jaws (even if an angle of ±2 mrad for each module is required in case of need). A significant reduction of setting up time is hence expected.

Difference between the TDI in Pt2 and Pt8

Higher impedance and stronger heating were observed in Pt8 for the BN version of the TDI. This was ascribed to the failure of the coated BN blocks. In the present TDI the pressure spikes when opening the jaws is more pronounced in Pt8. The effect shows conditioning.

The origin of the difference is unknown. The only difference which has been identified between the two devices at Pt2 and Pt8 is in the material which covers the aluminum alloy support of the graphite blocks: in one case it is copper plating (all surfaces coated) and in the other case is a thin film of titanium coating. Possibly a future inspection might reveal the origin of the difference in the behavior, but such an inspection is not considered as a priority.

T measurements

The temperature measurements were unreliable due to beam coupling.

Two possible effects are conceivable in the present case, RF induced noise and RF induced heating of the sensors. The latter seems less likely, since the temperature changes abruptly after beam dump (oral communication during the discussion after presentations) (see further 3.3).

3.2 The choice of the materials, heating, beam impact effect

There are three sources of deposited power and related temperature increase, one is the beam impact, the second is related to impedance and the occurrence of HOM and the third is in principle electron cloud. We treat in this section the first aspect and the others are treated in 3.3 and 3.4, respectively.

The low Z material

From thermo-mechanical calculations the selected graphite (SGL R7550 = R4550) ***has no margin*** *in case of a grazing incidence beam impact with HL-LHC parameters. However, the mechanical properties for such high strain rates are not well known and* ***the panel recommends*** *to perform* ***detailed simulation of dynamic stresses thermally induced by beam impacts in order to assess the worst scenario****.*

On top of that ***a dynamic characterization of mechanical properties (Graphite and CFC) as well as an investigation about fracture mechanics behavior of graphite based materials could help.***

In spite of the fact that graphite is already installed in the present TDI, the ***result of HRMT-28*** *test with BCMS beam impact is considered as crucial to assess the mechanical robustness.*

The choice of the selected type of graphite is compatible with the vacuum requirements if the material is properly treated before installation (vacuum firing).

The option of 3D carbon-carbon (3D CFC) would be compatible with the installed pumping speed to reach the specified pressure. It is a material which is not fully isotropic in the three direction, but has superior mechanical strength compared to graphite and sufficient margin to withstand the impact with the design post LS2 beam parameters and margin for beams with even higher brightness. The material will be ***tested in HRTM-28****. The possibly* ***higher impedance compared to graphite should be measured and its effect assessed****.* ***The panel recommends to review the results of the tests performed on LHC secondary collimators*** *(equipped with 2D CFC jaws AC150k from Tatsuno) in the TT40 line in 2004 and 2006 in order to have more data and to help in addressing the choice of a possible 3D CFC.*

Non-coated graphite is the present baseline*. Thin film coatings applied to graphite to reduce impedance (e.g. Ti underlayer + Cu layer) feature a high risk of damage upon beam impact and* ***should be tested as well in the HRMT facility through a dedicated test*** *to confirm their viability (see also §3.3).*

Other materials and energy deposition

Deformation upon heating can result from residual stresses in the materials upon manufacturing. The panel ***recommends*** *a careful* ***stress relieve*** *during the phases of manufacturing before assembly. This recommendation applies to non-low Z materials and* *might imply consequences for the selection of such materials, that should remain compatible with an eventual stress relieving heat cycle, namely for the aluminum alloy blocks (see also hereafter §3.7).*

The panel ***recommends*** *a simulation to verify the amount of* ***energy deposited in the cooling water*** *as well as in the pipes itself in case of a beam impact on the jaw. The resulting mechanical stress/strain (due to possible water pressure instantaneous increase) on the cooling pipes should be carefully evaluated.*

The panel recommends also to carefully verify the energy deposition on the aluminum alloy back stiffeners of the TDIS in case of beam impact *and to evaluate possible permanent plastic deformations with consequent permanent sag of the jaw (similar study performed in 2006 on LHC secondary collimators following TT40 tests). Possible alternative material (in place of aluminum alloy) to be identifies.*

For the high Z materials and for the stiffener there was an ***ambiguity on the identification of the temper*** *of the EN AW 5083 alloy presently used (H111?), since in the presentations lower reference tensile properties were claimed after the bake-out. The Al-alloy of the blocks shall withstand stresses expected to reach values of the order of 150 MPa at temperatures of 150-200 °C. However the total time at high temperature will be limited. Moreover, this material will see at least a bake-out at 300 °C, but possibly more in case of local venting. The presently selected EN AW 5083-H111 has the advantage of being non heat-treatable and in an annealed temper, hence its reference properties will not evolve as a function of stress relieving and bake-out. However, although this alloy is the one of the strongest in its category in the annealed temper,* ***its properties at 150-200 °C are not sufficient****. With a bake-out at 300 °C higher strength precipitation hardenable alloys will be overaged. Even EN AW 2219-T851, which has a large T range of use and one of the best performances at high temperature, will lose a significant fraction of its yield strength if heated at 300 °C*

*On the other hand****, if baking can be kept within 260 °C for example for 10 h****, a yield strength at RT after heating could be still above 200 MPa for the above alloy EN AW 2219-T851. For a permanent operation at 150 °C —200 °C under 150 MPa, there is not sufficient margin even one would not have degraded the initial yield strength by the baking operation. Indeed, even without a baking, 150 MPa at 200 °C will provoke a significant creep and even creep rupture after only 1000 h of operation. However,* ***for a short overall life at 150-200 °C*** *this alloy might still be considered.*

For the high Z part Ti-6Al-4V (Grade 5) blocks instead of aluminum alloy would be preferable for mechanical reasons and also for conditioning with respect to e-cloud. However, a ***simulation of the effect on the impedance*** *and resulting heating is necessary because of the lower electrical conductivity of this alloy compared with aluminum alloys.*

3.3 Impedance (RF fingers, tapering, jaws surface conductivity)

Impedance of the configuration

In general a significant impedance minimization has been applied to the TDIS, so that even for such a segmented design, where the geometrical impedance increases proportional to the number of gaps along the jaws, the overall impedance is lower than for the current TDI. This can be achieved thanks to the reduced transverse cross section of the TDIS and the large amount of RF-finger contacts which has been implemented to ensure beam screen continuity.

*The RF fingers - proposed to be produced in the (low Be) C17410 CuBe alloy, featuring improved resistance against stress relaxation, and Ag-plated - are an appropriate solution, but an **RF test with the stretched wire setup** must be done on the prototype in order to measure impedance. **HOM must be identified by simulation** and the sites where power is deposited must be carefully analyzed to prevent damages in sensitive locations (for instance RF fingers). **The worst case scenario (HOM frequency coincides with one of the beam harmonics) should be assumed** when analyzing the impact of the most critical HOMs on the deposited power and on the beam stability. Ferrite absorbers must be introduced to damp HOM if necessary.*

*On top of that, **the panel recommends to perform a specific experimental test via dedicated setup to validate the mechanical lifetime of the RF fingers** submitted to an imposed cyclic deformation (opening and closing of the jaws)**.***

Tapering

Tapering of the TDI jaws at the entrance, as in the current TDI, must be maintained.

Coating

*The difference copper coated/bare graphite blocks in terms of impedance (although it would be a significant contribution to the global budget of the machine: 0.5% for Z/n and 0.5% for Zyeff of the HL-LHC budget) does not affect the beam performance and is only an issue for the temperature rise in the device. Coating of the full face of the graphite blocks with 2 μm of copper would reduce the deposited power from approximately 676 W down to 55 W. In principle the cooling power is sufficient to cope with the highest value. **Calculations of the temperature rise should still be performed** by cumulating the RF heating from resistive wall (676 W), the most critical HOMs (~800W) and the heating due to e-cloud (maximum 250 W) as a function of the jaw position and the location of the heat deposition.*

*The benefit of a copper coating has to be compared with the risks of damages in case of grazing beam impact (the impact is more likely than for collimators). The worst case is a peel off of macroscopic particles which could hang or fall in the beam creating UFOs. The subsequent local lacking of coating is acceptable. **The HRMT-35 test, which is already foreseen, will enable a better evaluation of the risk of UFOs and the type of damage on the coating.***

The option of a partial copper coating leaving an uncoated stripe close to the beam would bring a negligible benefit, since the relevant effect is provided by the region which is closest to the beam. In addition the alignment and slight changes of orbit would not enable to envisage this option.

*A further option, with the **copper coating only on the lower jaw, should be evaluated**. In particular the benefit of this configuration in terms of impedance should be calculated. In terms of UFO such a solution would avoid falling particles. **The final decision must be taken also in this case by considering the results of the HRTM test.***

3.4 Electron cloud

The power due to e-cloud has been calculated for a wide range of SEY and can be added to the RF power for a more accurate simulation of thermal effects as a function of jaw position. For e-cloud issues the rationale is to rely on conditioning as for the other parts of the machine, so *that he deposited power will decrease with operation. For this reason aluminum alloy in the high Z material section shall be coated with a thin (0.5 µm) titanium layer, which can condition. The alternative, Ti-6Al-4V (Grade 5) blocks, would not need any coating.*

In terms of beam stability the TDIS is too short to affect the beam even in case of e-cloud.

***Studies of the present TDI are strongly recommended** (see 3.1) to understand the pressure spikes upon opening of the jaws in presence of the beam.*

3.5 Control: jaws positioning/alignment, interlocks temperature measurements

*The strategy of beam based alignment would be maintained. Instead of two separate jaws, three separate collimators would have to be aligned per injection region. Shorter collimators will be faster to set up despite the larger number. The absolute calibration of the LVDTs will also be beneficial. **The panel recommends to ensure the proper operation of the device and its protection both by software and by hardware, so that human errors can be prevented**. An adequate setting-up and verification procedure and/or software should be prepared to ensure that the higher Z TDIS module is indeed retracted by 2 mm with respect to the low Z modules. In addition a mechanical interlock solution (with micro-switches) should be studied, which prevents moving the high Z module beyond the 2 mm retraction position.*

The panel finds the redundant gap surveillance with an additional set of LVDTs to be adequate to be connected to the BETS. The option of an additional interferometer system is discarded.

*Possibility to integrate **BPMs in a collimator-like configuration should be carefully considered** before excluding this effective solution.*

*The temperature reading is mandatory to control the operation of the device, especially in the absence of copper coating of the graphite blocks, and understand possible malfunctioning. Sensors and cables carrying the signal should be properly shielded for any RF interference. **Shielded sensors should be first tested** and qualified in stretched wire measurement setup and implemented in the mechanical TDIS design.*

*In addition **the use of PT100 thermal probes requires particular care** to be paid for the mechanical integration, since the **thermal contact on the graphite** is influencing the measurement. The force of contact should be controlled to obtain a reliable measurement). The panel proposes to possibly explore the use of thermo-couples and fixed contacts to improve the reliability of temperature measurement of the jaw. Temperature calibration of the sensors before installation should also be considered.*

3.6 Recommended tests for the prototype

Perform vacuum test to assess the final pressure foreseen without beam.

Verify the effect of bake-out on dimensional stability (metrology).

Perform transverse and longitudinal beam coupling impedance measurements (in stretched wire test setup) and identification of HOM by simulations.

Perform multiple operational cycles from parking to protection settings, as well as tilting as during setting up to test the long term behavior of the new actuation system and of the many longitudinal and lateral RF fingers.

Perform measurements of possible beam interference on the temperature sensors in the stretched wire setup.

Perform if possible temperature calibration of the sensors before installation by comparing the measured and real jaw temperature.

3.7 Other issues

A pressure test is foreseen for the cooling system. The ***test should be carried out under - at least - moderate vacuum or dry air to*** *avoid humidity condensation on the pipes (corrosion issues for the couples aluminum-alloy/graphite and aluminum-alloy/CuNi pipes). The same is true in case of long time storage of the device on surface. This aspect is not relevant in operation under vacuum.*

In the region of the TDI in Pt2 and Pt8 of the machine the ***space should be preserved*** *in a way that after the installation of the new TDIS, the re-installation of the present TDI would still be possible. In particular no long term experiment or permanent diagnostics device should be installed in the space allocated to the present TDI.*

Improved solution ***concerning vacuum sectorization*** *for a quick replacement of future TDIS is highly valuable in terms of operation reliability.*

4 Final remarks and conclusion

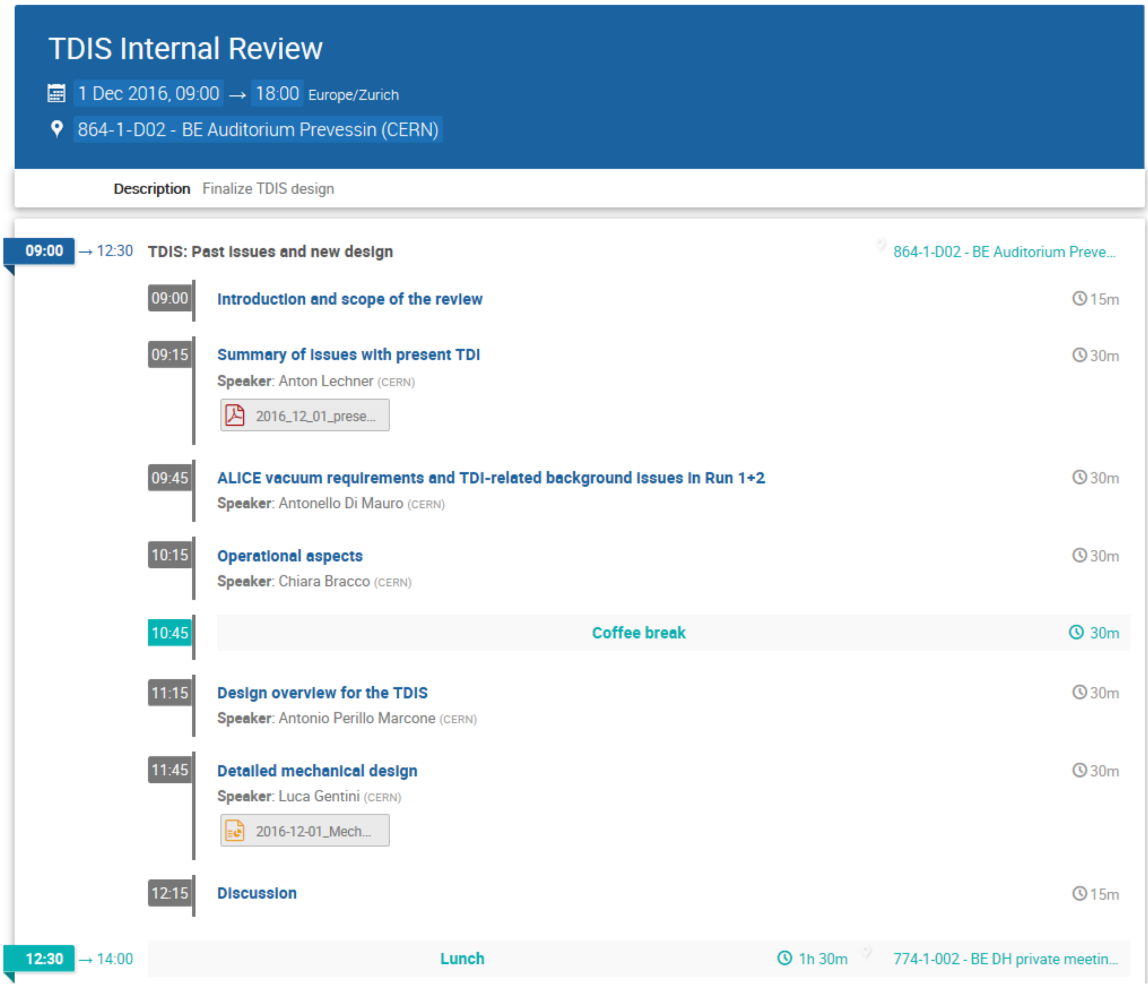
The Panel congratulates the review organization team to general high standard of the presentations and the proposed design of the TDIS. The design clearly addresses many of the issues of current TDI, most importantly the TDIS will be equipped with adequate cooling. The new configuration of the jaws segmented in 3 modules will guarantee an improved alignment of the device and a better thermo-mechanical stability.

Additional in-depth studies are recommended in order to assess best materials in terms of thermo-mechanical robustness (beam impacts) for jaws and back-stiffeners.

Comparative e-cloud simulations between current TDI and TDIS could help in understanding the vacuum spikes affecting the beam operation. This critical point should be possibly addressed before starting the TDIS manufacturing. Same recommendation concerning possible local heating due to impedance (and/or HOM).

5 Appendix:

5.1 Meeting agenda http://indico.cern.ch/event/579995/timetable/



TDIS Internal Review

1 Dec 2016, 09:00 → 18:00 Europe/Zurich

864-1-D02 - BE Auditorium Prevessin (CERN)

Description Finalize TDIS design

09:00 → 12:30 **TDIS: Past issues and new design** 864-1-D02 - BE Auditorium Preve...

09:00 **Introduction and scope of the review** 15m

09:15 **Summary of issues with present TDI** 30m
Speaker: Anton Lechner (CERN)
2016_12_01_prese...

09:45 **ALICE vacuum requirements and TDI-related background issues in Run 1+2** 30m
Speaker: Antonello Di Mauro (CERN)

10:15 **Operational aspects** 30m
Speaker: Chiara Bracco (CERN)

10:45 **Coffee break** 30m

11:15 **Design overview for the TDIS** 30m
Speaker: Antonio Perillo Marcone (CERN)

11:45 **Detailed mechanical design** 30m
Speaker: Luca Gentini (CERN)
2016-12-01_Mech...

12:15 **Discussion** 15m

12:30 → 14:00 **Lunch** 1h 30m 774-1-002 - BE DH private meetin...

14:00 → 18:00 **TDIS: FLUKA/ANSYS studies, impedance, e-cloud and vacuum** 864-1-D02 - BE Auditorium Preve...

14:00 **Energy deposition studies for HL beams** 30m

Speaker: Matthias Immanuel Frankl (CERN)

2016_01_12_tdis_r...

14:30 **Thermo-mechanical studies for the TDIS jaws** 30m

Speakers: David Carbajo Perez (Universidad de Oviedo (ES)) , Inigo Lamas Garcia (CERN)

20161201_FEA_TD...

15:00 **Lessons learnt from the present design and impedance evaluation of the TDIS** 30m

Speakers: Benoit Salvant (CERN) , Nicolo Biancacci (CERN)

TDIS_review_impe... TDIS_review_impe...

15:30 **Coffee break** 30m

16:00 **E-cloud related aspects** 30m

Speakers: Galina Skripka (CERN) , Giovanni Iadarola (CERN)

40mmgap_density.... 4mmgapmovie.gif e_distribution.mp4 TDIS_HiLumi.pdf TDIS_HiLumi.pptx

16:30 **Vacuum performance of candidate materials for the TDIS** 30m

Speakers: Giuseppe Bregliozzi (CERN) , Josef Sestak (CERN)

TDIS_Review.pdf TDIS_Review.pptx

17:00 **Discussion and final remarks** 1h