European Organization for Nuclear Research
*Organisation européenne pour la recherche nucléaire*

**IT-4029/PH/ALICE**

***The ALICE ITS Upgrade Project***

# Invitation to Tender

# Technical Specification

Supply of automatic assembly systems for the Hybrid Integrated Circuits of the ALICE ITS and MFT upgrade projects


## Abstract

This technical specification concerns the supply of automatic assembly systems for the so-called Hybrid Integrated Circuits of the ALICE ITS and MFT upgrade projects.

The systems shall allow large surface silicon dies pick and placement, with an accuracy of ±5 μm at 3σ, by an operator using stages controlled by a console and sensor system assistance. In addition, interconnection of silicon dies and flexible printed circuits shall be performed automatically by laser soldering of 200 μm soldering balls.

Deliveries are foreseen over 1.5 years from placement of the contract.


October 2014

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# 1. INTRODUCTION

## 1.1 Introduction to CERN

CERN, the European Organization for Nuclear Research, is an intergovernmental organization with 21 Member States[1].

Its seat is in Geneva but its premises are located on both sides of the French-Swiss border (http://cern.ch/fplinks/map.html).

CERN's mission is to enable international collaboration in the field of high-energy particle physics research and to this end it designs, builds and operates particle accelerators and the associated experimental areas. At present more than 11 000 scientific users from research institutes all over the world are using CERN's installations for their experiments.

The accelerator complex at CERN is a succession of machines with increasingly higher energies. Each machine injects the beam into the next one, which takes over to bring the beam to an even higher energy, and so on. The flagship of this complex is the Large Hadron Collider (LHC) as presented below:

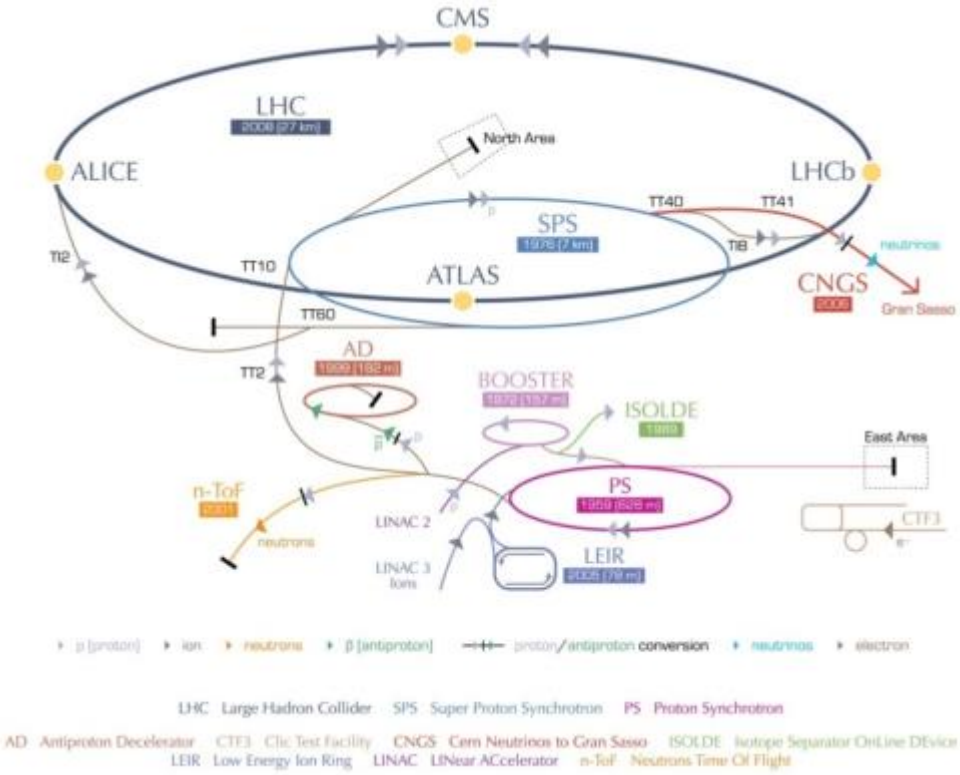



Figure 1: CERN Accelerator Complex

Further information is available on the CERN website: http://cern.ch .

[1] The CERN Member States are currently Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and United Kingdom. In addition: Serbia is Associate Member State in the pre-stage to Membership and Romania is Candidate for Accession.

## 1.2 Introduction to the ALICE ITS and MFT Upgrade Projects

ALICE, or A Large Ion Collider Experiment (http://aliweb.cern.ch/), is a heavy-ion physics experiment at the Large Hadron Collider (LHC) at CERN. The ALICE detector is designed and constructed to study the matter under extreme conditions of temperature and density created in head-on collisions of heavy nuclei produced by the LHC at unprecedented high energy. ALICE investigates the basic properties of primordial matter from which the today's Universe has emerged and which prevailed for a fleetingly short time just after the Big Bang. The fundamental questions that ALICE tries to answer are, among others, about the origin of the mass of ordinary matter, how the strong force organizes the elementary constituents of matter, what is the structure of vacuum associated to the strong force and how did primordial matter turn into ordinary matter. The ALICE detector is located in an underground cavern on the French part of CERN. The experiment is in operation and produces physics results since December 2009. The ALICE collaboration involves around 1200 scientists from 132 institutions in 36 countries.

In the context of the ALICE central barrel detectors upgrade, planned for the 2$^{nd}$ long shutdown of LHC (2018-19), a new low material and high-resolution silicon pixel detector for the Inner Tracking System (ITS) and for the Muon Forward Tracker (MFT) will be built. Such new detectors will have greatly improved features in terms of spatial resolution for primary vertex reconstruction, tracking efficiency (at low transverse momentum, $p_T$) and readout rate capabilities.
The new ITS silicon tracker consists of 3 inner layers (for the Inner Barrel, IB), 2 middle layers and 2 outer layers (for the Outer Barrel, OB) of monolithic pixel sensors. Schematic layouts are shown in Figs. 1 to 3.

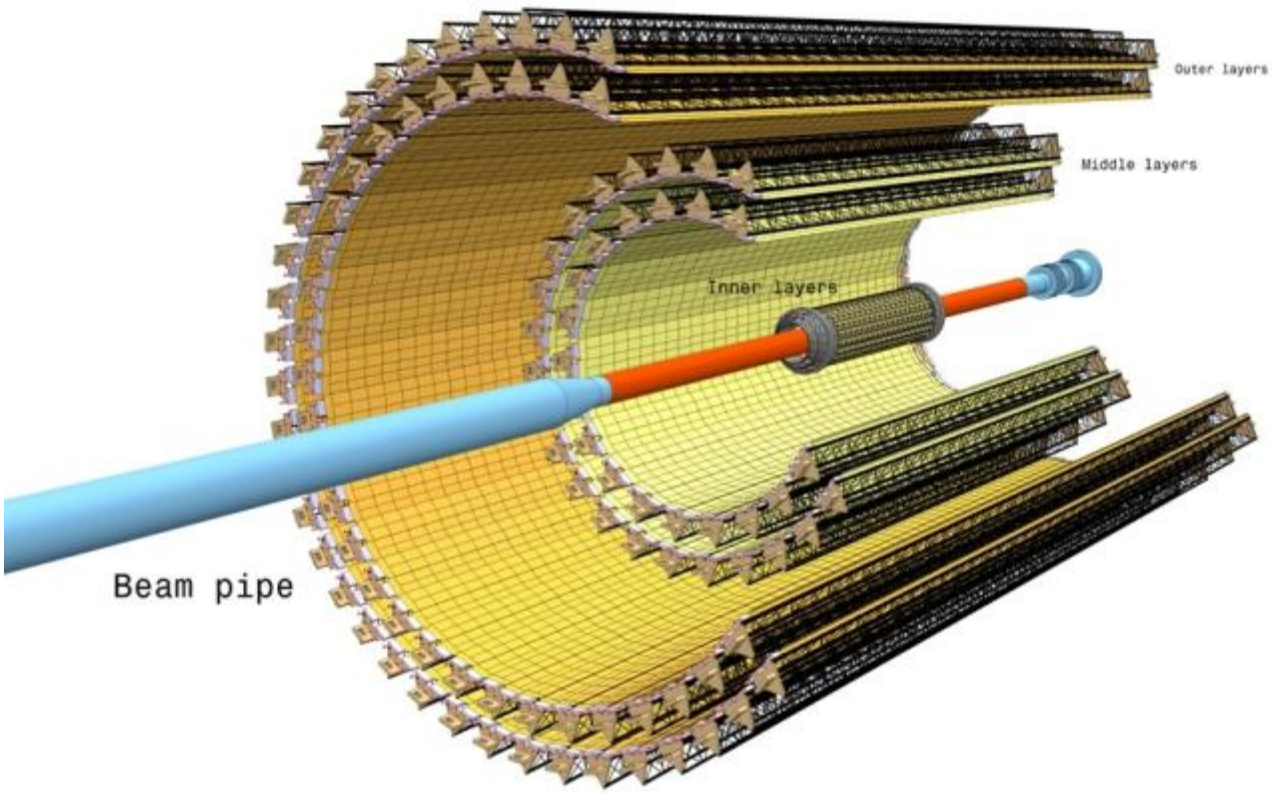



**Fig. 1 Schematic picture of the full ITS detector.**

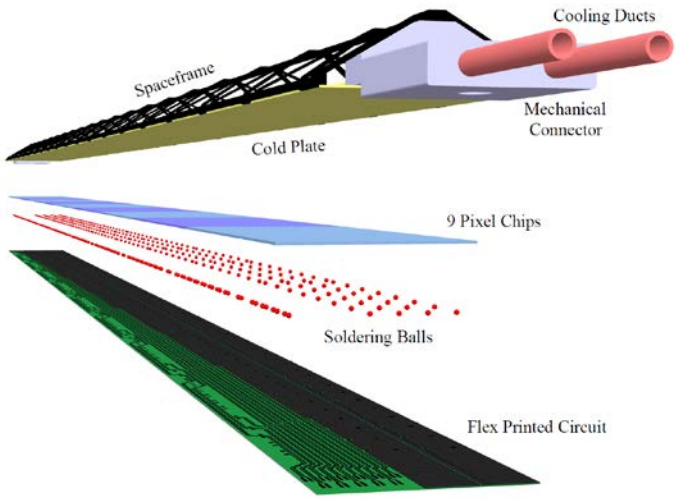



**Fig. 2 Exploded view of the ITS Inner Barrel staves.**

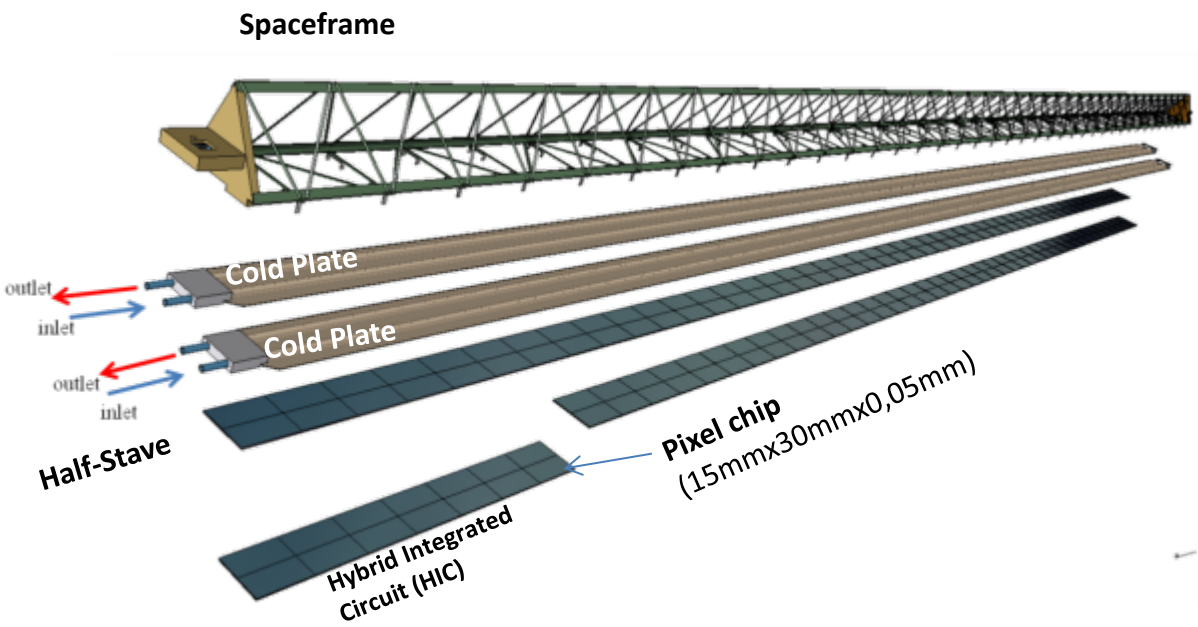



**Fig. 3 Exploded view of the ITS Outer Barrel Stave.**

The MFT consists of 5 planes of same monolithic pixel sensors as for the ITS. Fig 4 shows the schematic general layout of the MFT planes and Fig. 5 illustrates the exploded view of one MFT plane.

The so-called ***Hybrid Integrated Circuit*** (**HIC**) is the key element of the new ITS and MFT detectors and it has to fulfil very specific requirements: minimal material budget and high accuracy of chips position. It is a structure consisting of a ***Flexible Printed Circuit*** **(FPC)** board, having 75 μm thick polyimide coated with 25 μm thick Al or Cu on both faces, and one row of 9 silicon chips or two rows of 7 silicon chips for the IB and OB, respectively. The MFT HIC structure consists of various lengths of FPC boards equipped with 1 to 5 chips in a row.

Some redundancy in the quantity of HICs to be produced is required, specifically 120% for the IB, 20% for the OB, and 80% for the MFT planes resulting in the following quantities:

1) IB: 106 "*9-chips*" HICs (954 chips to be soldered)
2) OB: 2030 "*14-chips*" HICs (28420 chips to be soldered)
3) MFT: 505 "*1 to 5-chips*" HICs (1630 chips to be soldered)

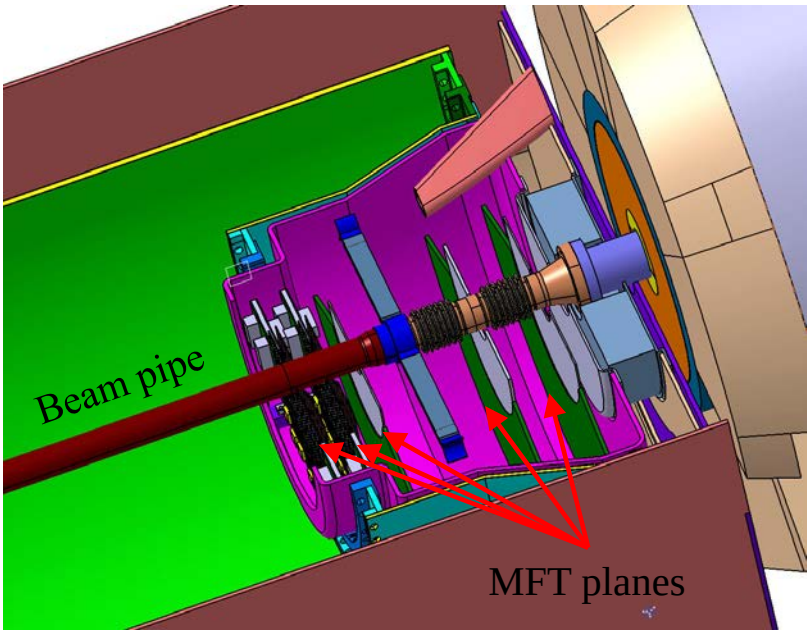



**Fig. 4 Schematic picture of the full MFT**

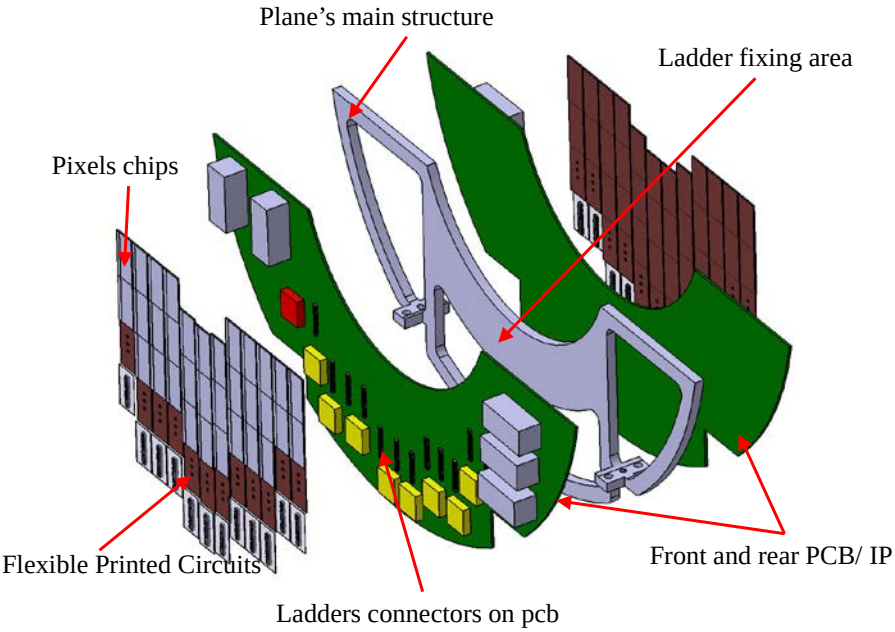



**Fig. 5 Exploded view of one MFT plane**

***Summary of chip characteristics***

The silicon chips are used without encapsulation and the contact pads to be soldered are realized directly on the silicon surface. The chips measure 30 mm x 15 mm and are thinned to 50±5 μm

thickness. The dicing currently is performed by blade, achieving a tolerance of -0/+30 μm on the chip dimension (laser dicing is under consideration to improve this figure to -0/+10 μm). On the chip, all connection pads are located on the top surface: power supply connections are distributed over the full chip surface while I/O connections are concentrated along the bottom edge of the chip, as schematically sketched in Fig. 6. The chip connections are made of round aluminium pads, having 300 $\mu$m diameter and a pitch of ~ 1-2 mm, coated by a layer of Ni and Au for proper wetting of the soldering balls. Presently, the number of contacts per chip is not yet fixed; it will vary in the range between 80 and 100. On the top surface, reference markers are implemented at the four corners and along the edges to be used for precise positioning of the chips (Fig. 7). In the present layout, the marker starts 15 μm from the nominal edge and the distance of the centre point of the cross to the nominal edge is 50 μm. The exact position of edge markers will be fixed later and communicated to the contractor.

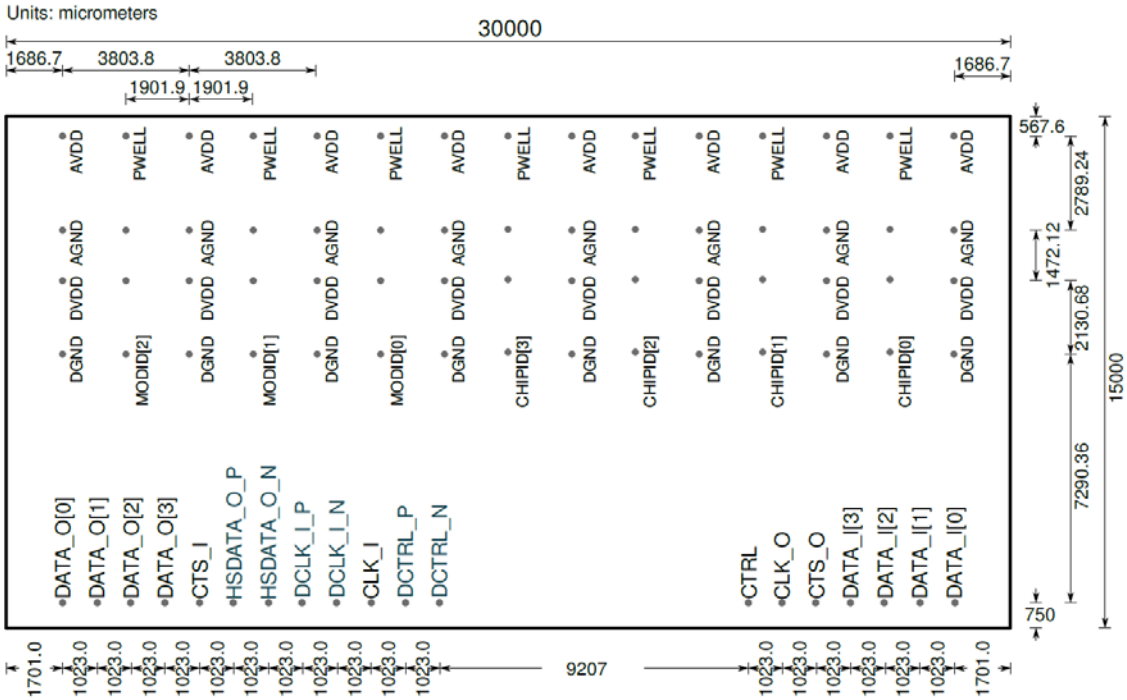



**Fig. 6 Schematic layout of connection pads on the top surface of the pixel chip.**

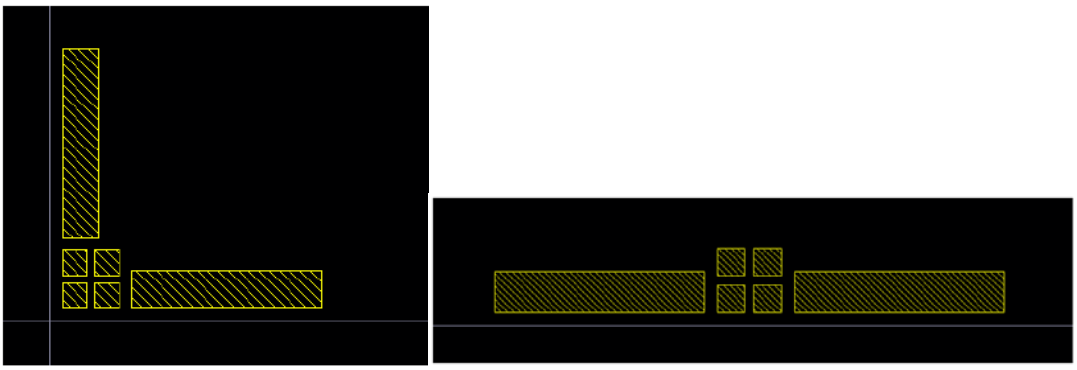


**Fig. 7 Magnified picture of sample chip reference markers at one corner (left) and along one edge (right).**

The silicon chips are characterized by a slight warp likely resulting in a concave shape with the four corners bending up by about 0.5 mm, as shown on a full size prototype chip in Fig. 8.

**Fig. 8 Picture of a silicon chip prototype (so-called pAlpide_FS): the concave shape is well visible.**

Finally, all chips are identified by a serial number to be used during all assembly phases for data storage.

***Silicon chips storage trays***

The silicon pixel chips will be stored in trays, from the wafer thinning and dicing up to the interconnection to the FPC. Two solutions are under evaluation for the storage: a) boxes with anti-static EPP (similar to Styropor) which can be ordered in different sizes (Fig. 9); b) Waffle Packs in ChipSentry® material, only in standard 4x4 chips format.

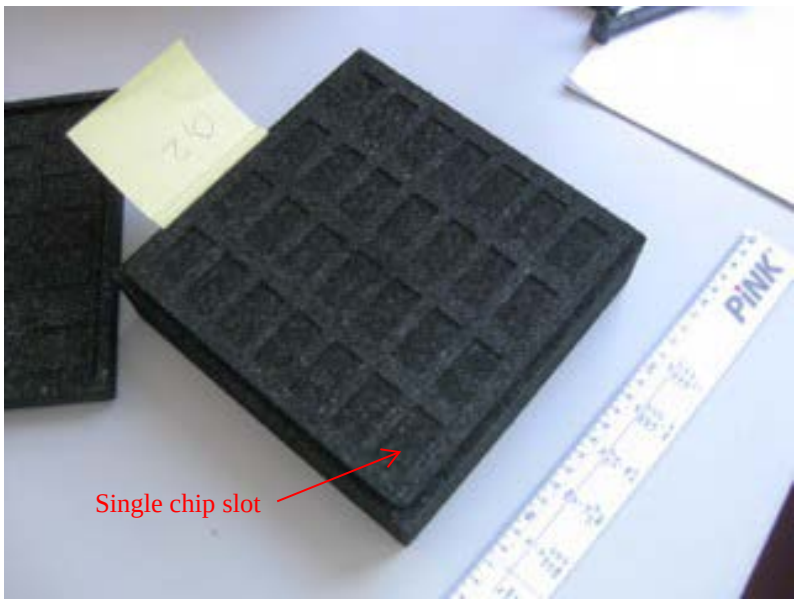



**Fig. 9 A photo of the EPP storage box with 4x7 chip slots.**

***Summary of FPC characteristics***

Very thin (~ 150 μm) FPC boards, with conductive tracks either in standard copper (for the OB) or using novel aluminium-based technology (for the IB and the MFT), will be used. The FPC holes, 220±10 μm diameter, are also metalized and coated with Ni/Au. A variation of hole's positions

within ± 50 μm over the full FPC length has been observed; a procedure to improve the position accuracy is under study. Two openings of 0.4x1 $mm^2$ and one of 1x1 $mm^2$ are available for each chip location in order to measure the position of underlying chips. Fig. 10 shows a photograph of an FPC prototype for the IB, while Fig. 11 shows the layout drawings of the final version of the FPC for both IB (top) and the details of the openings for chips reference markers (bottom). A picture of the OB FPC is reported in Fig. 12.
The MFT will have slightly different geometry of FPCs, with various lengths (related to the various number of pixel chips soldered, from 1 to 5).

***Summary of interconnection technique***
The interconnection joints between the chips and the FPC will be performed by means of selective laser soldering using 200 μm diameter Sn/Ag (96.5/3.5) balls, without flux and under vacuum ($\leq 10^{-1}$ mbar), according to the scheme presented in Fig. 13. Usage of Sn42Bi for the soldering balls is under investigation, as this alloy has a lower melting point than Sn/Ag (163 $^{o}$C instead of 227 $^{o}$C) and then would allow reducing the thermal stress induced by the soldering on the silicon chip. A soldering mask (in MACOR® or in $Al_2O_3$) with conical holes is used to press gently the FPC on top of the chip surface and guide the soldering balls inside the FPC holes. The laser spot size can be optimized and the region to be heated can be precisely limited and restricted to the minimum necessary for good wetting of the contact pads and FPC holes. An I.R. diode laser (976 nm, 25 W) is being used for the development of the interconnection process; the laser power is modulated by a pyrometer connected via a feedback loop to the system. Presently, in the optimized layout the focal length is 50 mm and the laser beam is focused from 25 mm down to 0.25 mm. The temperature profile is customized in order to get 100% reliable joints and to minimize thermal stresses on the silicon chips. Fig. 14 shows a top view from the camera of the laser system of a soldering ball placed inside an FPC hole and the corresponding joint. A photo of a cross section of a solder joint of a sample HIC is reported in Fig. 15; the good wetting of the solder to the chip pad and the FPC hole can be clearly seen. Fig. 16 shows an example of the soldering process diagnostic graph with the set temperature profile and the measured laser power and temperature.

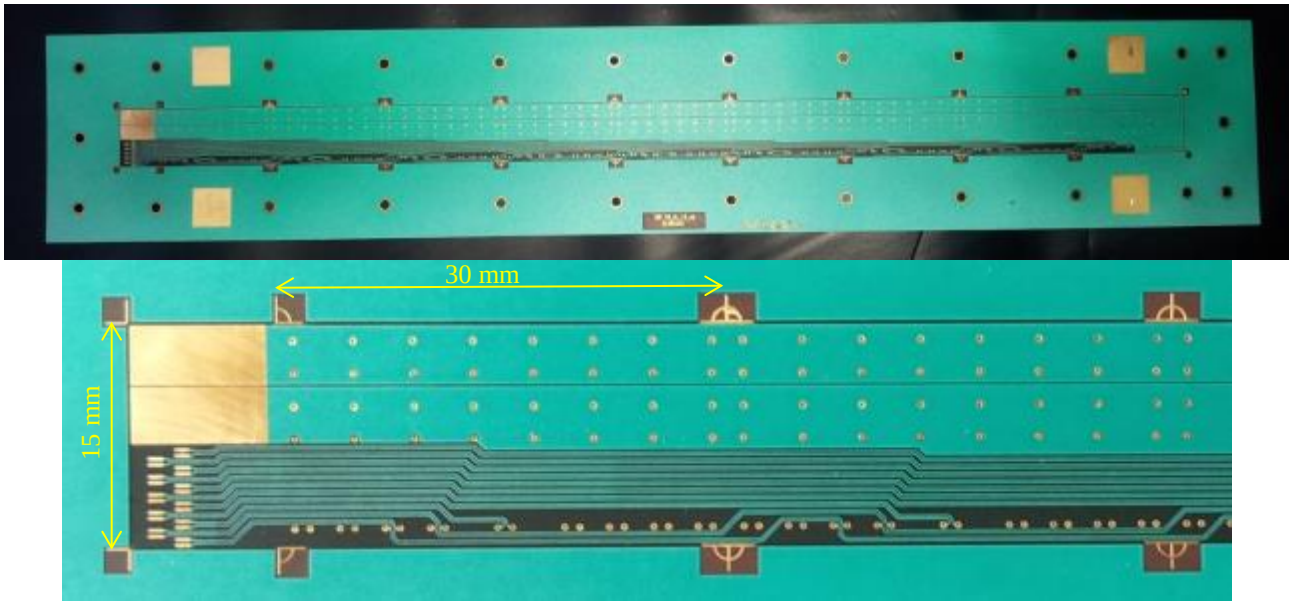



**Fig. 10 Full size view (top) and detailed view (bottom) of a 9-chip FPC prototype for ITS IB.**

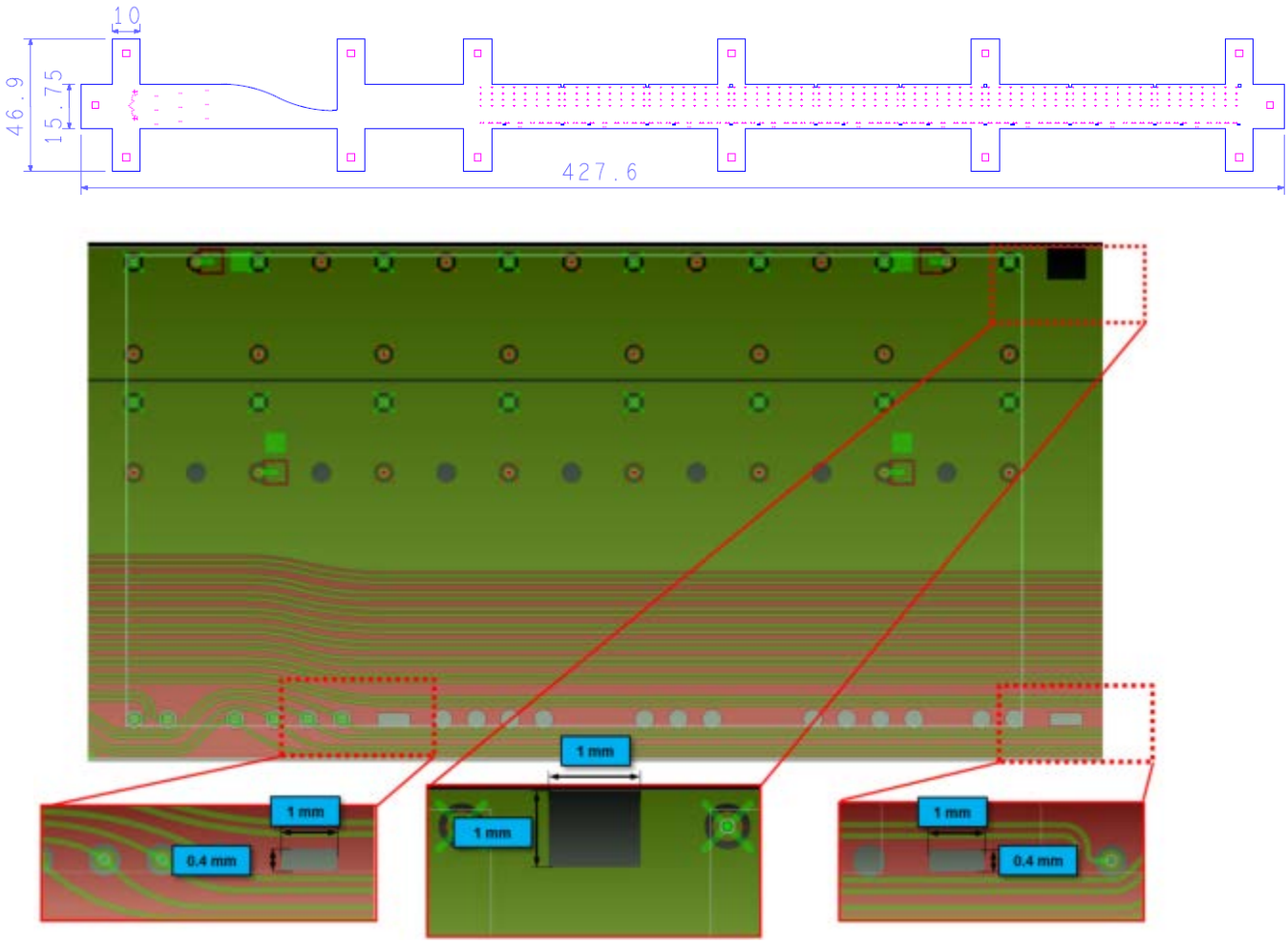



**Fig. 11 Final layout of IB FPC (top) and detailed view of openings for inspection of position of underlying chips (bottom).**

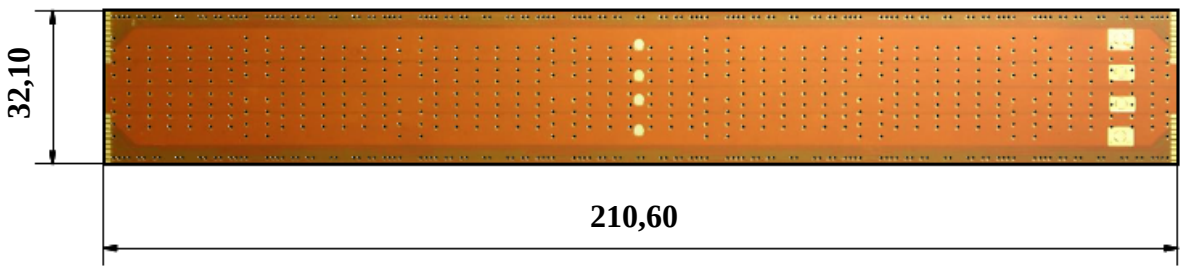



**Fig. 12 Picture of OB FPC prototype, dimensions are the same as in the final layout.**

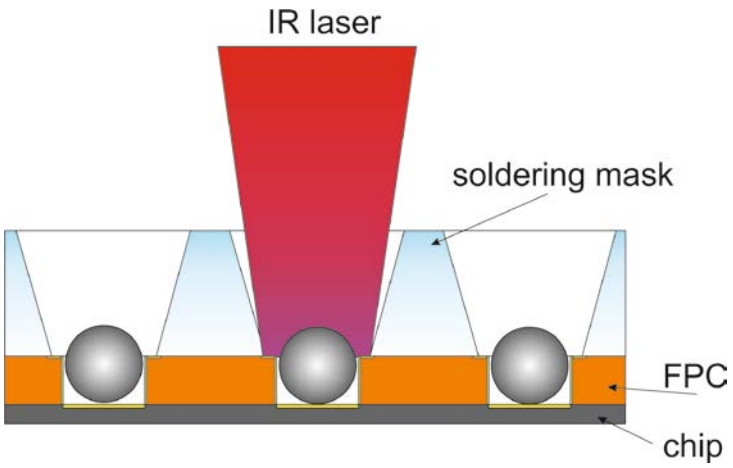



**Fig. 13 Schematic layout of parts arrangement for laser soldering (not to scale).**

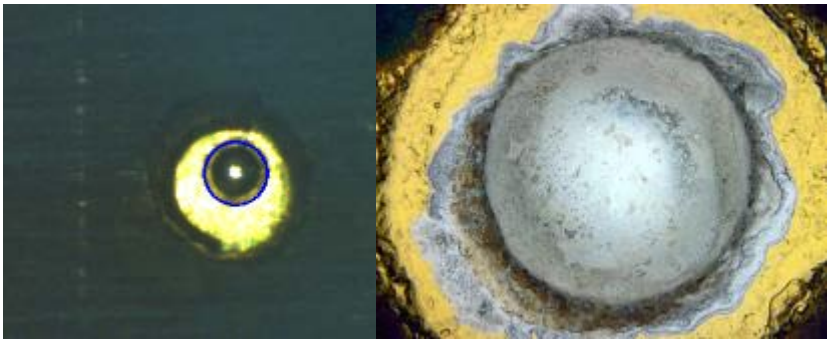


**Fig. 14 top view from of a soldering ball inside an FPC hole (left) and the corresponding joint obtained by laser soldering (right).**

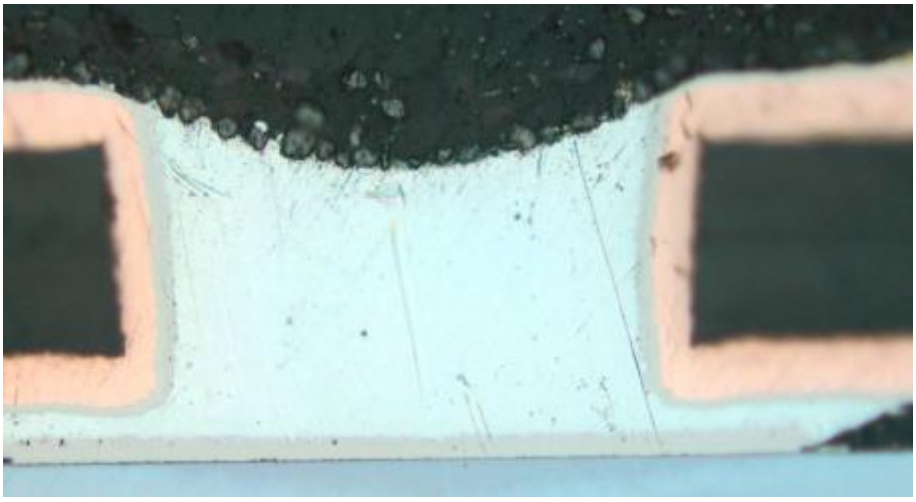


**Fig. 15 Metallographic inspection of a solder joint of a sample HIC.**

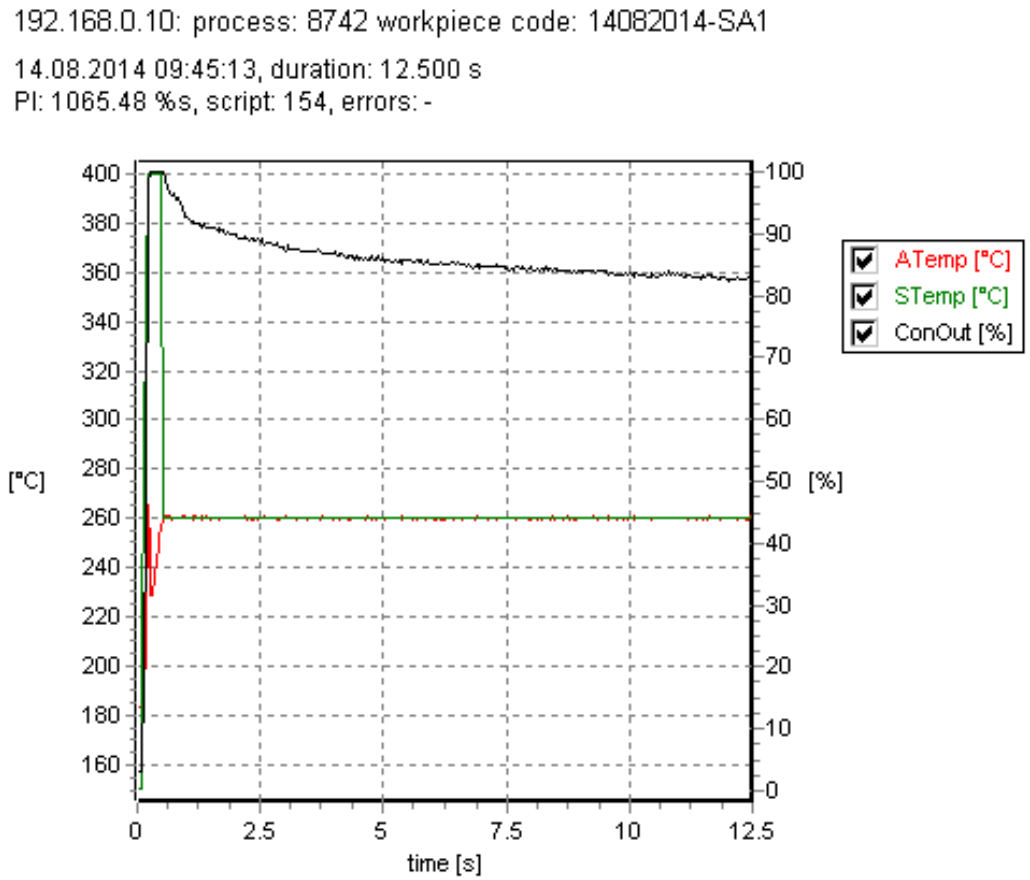



**Fig. 16 Example of laser soldering process profile: STemp is the set temperature, ATemp is the measured temperature and ConOut is the power supplied to the laser diode (© Dr Mergenthaler GMBH & CO).**

## 2. SCOPE OF THE SUPPLY

The successful bidder (hereinafter referred to as the "contractor") shall supply the Automatic Assembly Systems for the Hybrid Integrated Circuit of the ALICE ITS and MFT upgrade projects (hereinafter referred to, in whole or in part, as the "supply") as defined in this technical specification and the documents attached to it. Such a supply shall perform silicon chips placement with an accuracy of ±5 μm at 3 σ with respect to a fixed external reference, interconnection of chips and FPC by laser soldering, quality control inspections by vision system and assembly data storage.

The supply shall originate from CERN and ALICE Member States, and under certain conditions, from Associate Member States or the Candidates for Accession (as specified in the tender form).

### 2.1 Deliverables Included in the Supply

The supply shall include:

- prototype of HIC automatic assembly system to be installed at CERN in the French site in Meyrin;
- upon acceptance of a prototype system, delivery of three series production systems to be installed respectively in Italy (Bari), France (Strasbourg) and South Korea (Pusan);
- documentation on sub-systems and usage procedures.

The following subsystems shall be supplied by the contractor and integrated in the assembly system: a) moving stages and grips; b) sensor system; c) laser system LH2501 and LASCON Hybrid from Dr. Mergenthaler GMBH & CO; d) a flat screen of suitable size and a PC for control and monitoring tasks; e) ionizer; e) vacuum system; f) electrical control and operator interfaces; g) mechanical structure and cabinet.

## 2.2 Activities at the contractor's Premises

The contractor shall perform the following activities at his premises:

- Design;
- Prototyping and intermediate tests for design validation;
- Tests of prototype;
- Series production and related testing;
- Packing;
- Shipping.

The series production shall not start before CERN has given its formal approval of the prototype in writing.

## 2.3 Activities on the CERN Site and other HIC production sites included in the supply

The contractor shall execute the following activities on the CERN French site in Meyrin:

- Installation and commissioning of prototype;
- Personnel training;
- Preventive maintenance (during the warranty period);
- Corrective maintenance (during the warranty period).

The contractor shall execute the following activities on each of the other HIC production sites:

- Installation and commissioning of HIC automatic assembly machine;
- Personnel training;
- Preventive maintenance (during the warranty period);
- Corrective maintenance (during the warranty period).

## 2.4 Items and Services provided by CERN

CERN will provide the following items and services:

- One set of tooling for laser soldering, namely the so-called "HIC assembly table" and "soldering ball transfer tool" described in Section 3.3, for each system to be supplied;
- Two needle probe cards and related readout system for chip testing to be integrated in the prototype system and in one system of the series production, in case the corresponding option is selected;
- Samples of chips, soldering balls and FPCs for assembly tests.

## 2.5 Options

A first purchase option concerns an additional quantity of up to three systems, to be installed in UK (Liverpool), China (Wuhan) and USA (Berkeley, CA), respectively.

The following options, which will be described in Section 3.6, shall be quoted separately (see Tender Form):

- automatic placement of chips on vacuum chuck, in addition to the baseline semi-automatic operation mode;
- electrical test of chips using a probe card system, to be integrated in two HIC assembly systems;
- automatic transfer of soldering balls from a container into the holes of the aligned soldering grid and FPC;
- quality control of soldering joint by vision system.

# 3. TECHNICAL REQUIREMENTS

## 3.1 Introduction

The production of a HIC consists of a sequence of operations; some of them will have to be controlled or automatized in order to achieve the specified position accuracy and to ensure a reproducible quality.

Special tooling has been developed for the HIC production and will be supplied by CERN to the contractor for the integration in the automatic assembly systems. The prototype machine will be equipped in order to produce any of the three HIC types, while the other machines will be devoted to the production of OB HICs. However, all machines shall be configurable for the three types of HICs.

## 3.2 HIC assembly procedure and main technical requirements

The baseline HIC assembly procedure which shall be implemented for the supply consists of a sequence of tasks listed hereafter:

1) ***Chips alignment (semi-automated).*** Chips shall be picked by a suitable vacuum grip from the chip pallet and placed above the vacuum chuck in the HIC assembly table, described in Section 3.3. The chips shall be placed in nominal positions defined with respect to the two reference pinholes on the assembly table and aligned to each other with a gap of 100 μm between nominal edges, namely of 200 μm between the centre point of cross reference markers. **A tolerance of ± 5 μm at 3σ** is required in the position of each chip in the XY plane with respect to the external reference (absolute alignment). This operation shall be performed by the operator using a console to control the moving stages and the chip grip, with the assistance of the sensor system to establish whether the chips are at the desired position. A suitable chips pallet shall be implemented allowing the operation for all layouts of the HIC to be produced (ITS IB: 9x1; ITS OB: 7x2; MFT: 5x1, 4x, 3x1, 2x1, 1x1). Special care shall be paid to the design of the pallet and of the chips grip to take into account the mentioned chips warp which will affect the accuracy of the process if not treated properly. Also, chips quality control by the sensor system, as described later in Section 3.4, shall be implemented during this phase, either before or after the placement on the vacuum chuck; the details will be discussed and agreed upon with the contractor during the design stage.

2) ***Placement of FPC/soldering grid (manual).*** The FPC and the soldering grid (described in Section 3.3) stack are placed manually above the chips by the operator in positions defined by locating pinholes. The final tolerance on FPC holes position is not yet known, since the production process is still under optimization; presently it is of the order of ± 50 μm over the full FPC length, i.e. from the first to the last hole. Since the FPC hole diameter is 220±10 μm and the chip contact pads diameter is 300 μm, it will be possible to present all holes in front of the corresponding pad, although not perfectly centred.
3) ***Soldering balls placement (manual).*** The soldering balls corresponding to one chip are distributed inside the holes of the soldering grid manually by the operator using the balls transfer tool, described in Section 3.3. This operation, assisted by the vision system as described in Section 3.4, is repeated in sequence until all holes are filled.
4) ***Assembly table lid fixation (manual).*** After all soldering balls have been correctly deposited, the operator tightens the lid equipped with the quartz window, described in Section 3.3, on top of the soldering table and starts the vacuum pump. The pressure of the chips vacuum chuck shall always be smaller than the soldering vacuum (Section 3.4).
5) ***Laser soldering (fully automated).*** When the pressure is below 2-3 x $10^{-1}$ mbar, the laser soldering is started by the operator and each interconnection is automatically performed in sequence. **A tolerance of ±30 μm at 3σ** is required in the positioning of the laser head.

## 3.3 Description of deliverables supplied by CERN

The following items will be supplied by CERN to the contractor free of charge and shall be integrated in the supply.

***The HIC assembly table.***

Three different assembly tables shall be used depending on the type of HIC to be assembled (IB, OB or MFT). In general the such a table consists of a stack of stainless steel frames:

- A *base plate* in which a vacuum chuck is implemented to hold chips in place. The shape of the vacuum chuck as well as the number of vacuum channels to be controlled independently depends on the number of chips to be mounted (9, 14 or 5). Two pinholes on such a plate will be used as reference for the accurate positioning of the chips. In addition fiducial markers for each chip position could be drawn as solution to improve the placement accuracy. The surface of the vacuum chuck, machined with a flatness of 0.01 mm, is covered by a thin layer of thermally insulating material (e.g. high-T polyimide, MACOR®,…) and recessed by 0.05 -0/+0.005 mm to allow a perfect alignment of the chips with the top surface of the base plate. The choice of such a material shall be agreed with the contractor on the basis of EMC and ESD requirements, which shall be valid for the full system. Also, the fixation of the plate to the system will be agreed with the contractor.
- A *soldering grid* frame including a ceramic material plate (in MACOR® or in $Al_2O_3$) 0.5 mm thick, with holes of 0.5 mm centred on the positions of the FPC vias. Such a frame is used to hold the FPC and place it in a pre-defined position, pressing it gently on the chip surface to minimize the air gap in between. In addition it has pin-holes for the positioning

and alignment of the soldering balls transfer tool (described later). Finally, the grid holes are used to guide the soldering balls into the FPC vias.

- A *closing lid* equipped with a quartz window (Wisag® HOQ-310). Such a lid is used to confine the volume around the chips and the FPC (hereafter called "soldering volume") where a vacuum of the order of $10^{-1}$ mbar is necessary to perform the laser soldering in reliable and reproducible way. It is equipped with an opening to allow the connection to the vacuum system or to flush $N_2$ for purging.

Presently the holes for vacuum or gas have a diameter of 6 mm; this parameter as well as the type of fittings will be discussed and agreed upon with the contractor during the design stage.
Fig. 17 and 18 show photographs of the IB assembly table and soldering grid prototypes, respectively. Schematic drawings of final versions with main dimensions for the IB and OB are presented in Figs. 19 and 20, respectively. The MFT table will be similar to the IB one but shorter, as the maximum number of chips is five.

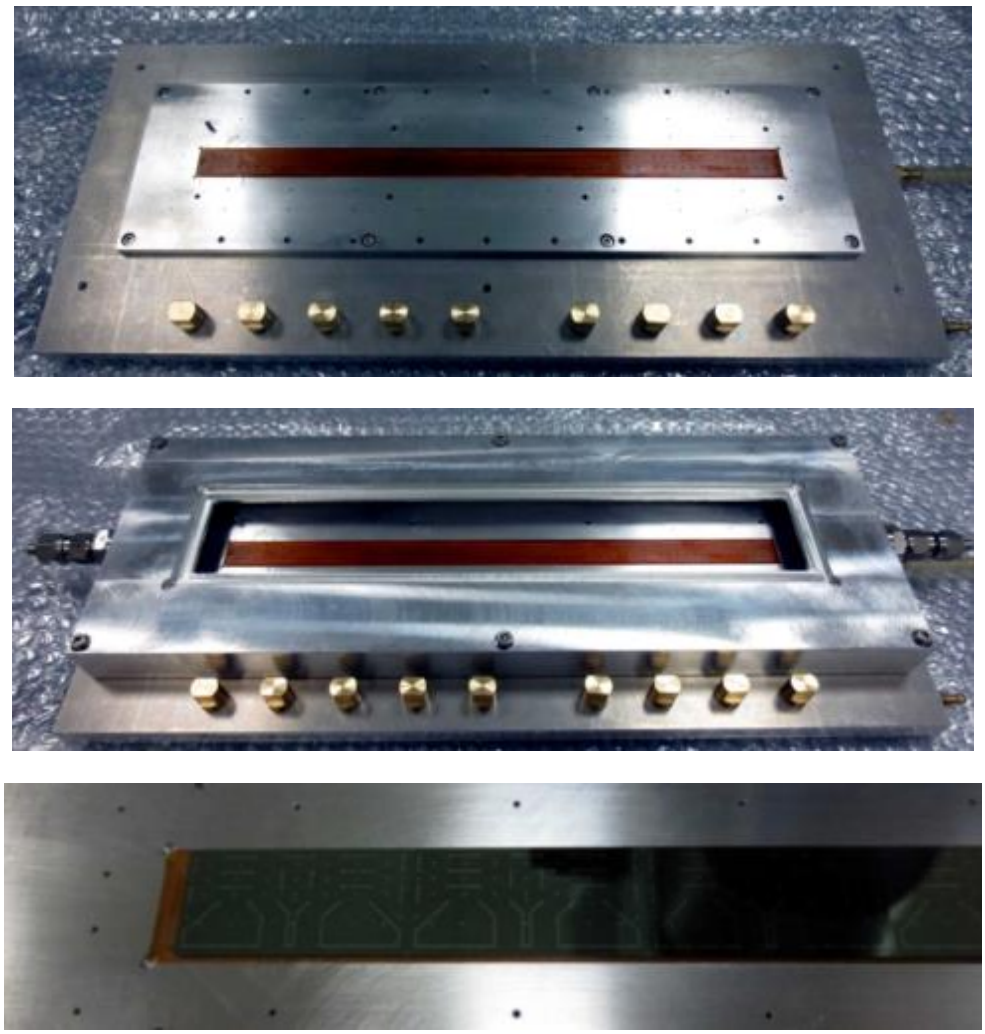


**Fig. 17 (Top) Picture of a prototype of the ITS IB base plate with the chip vacuum chuck in the middle and the 9 manual valves to control the vacuum in each of the 9 chip positions. (Centre) Picture of base plate and closing lid. (Bottom) The base plate with aligned dummy chips on the vacuum chuck.**

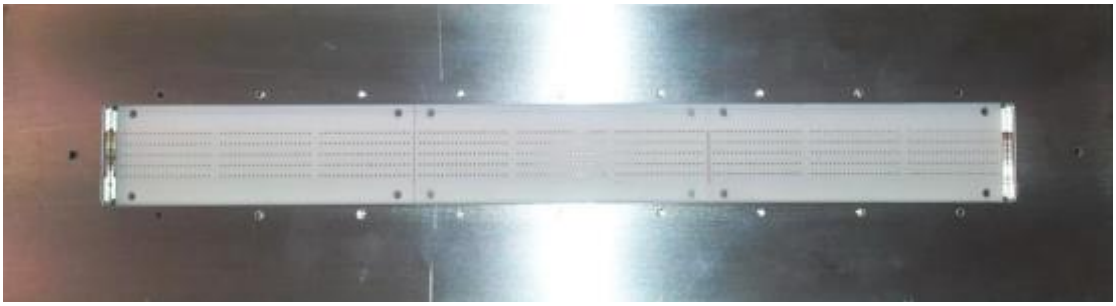


**Fig. 18 Picture of the IB 9-chips soldering grid prototype.**

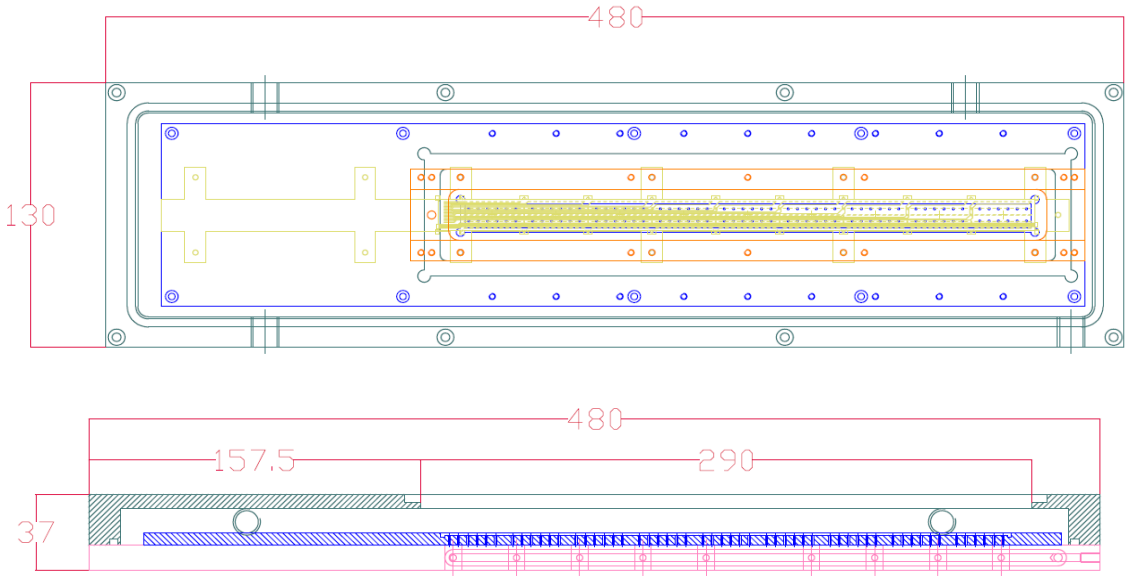



**Fig. 19 Drawing with top view and lateral section of the ITS IB assembly table.**

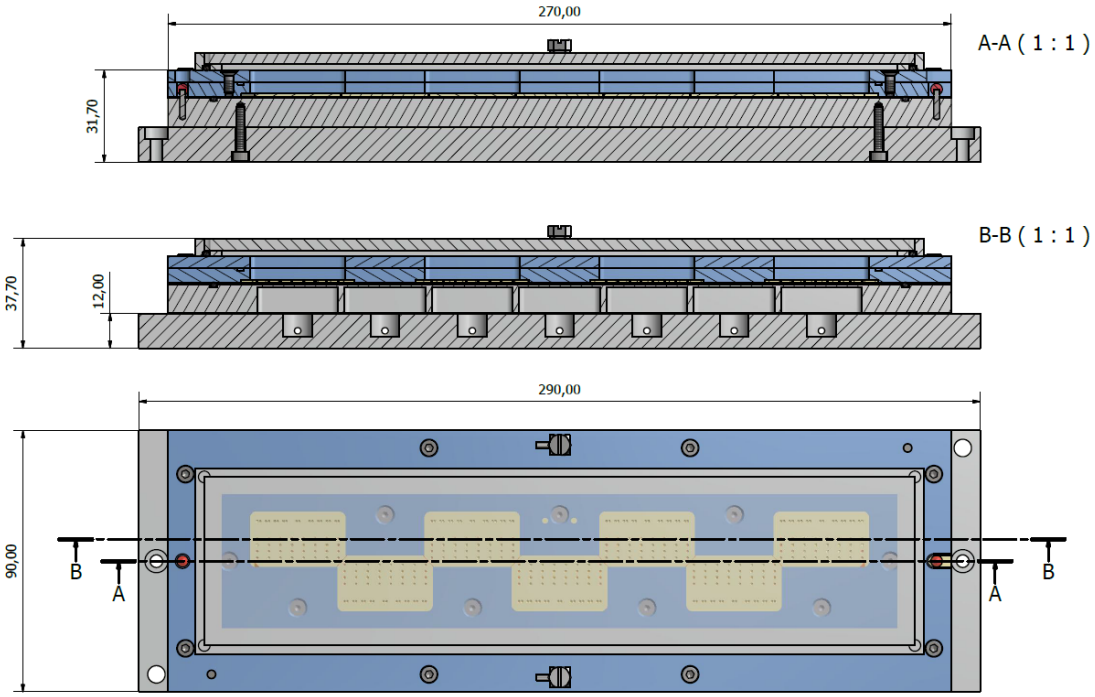



**Fig. 20 Drawing with top view and lateral sections of the ITS OB assembly table.**

***The soldering ball transfer tool.***
The soldering ball transfer tool has been designed to load the Sn/Ag balls into the FPC holes through the soldering grid frame. It consists of a Peek plate, mounted on a stainless steel vacuum chuck, and equipped with a matrix of 100 μm diameter holes matching the layout of FPC vias, hence of the chip contact pads (Fig. 21). The 200 μm diameter balls are loaded by vacuum onto the tool holes; after placing the tool in the position relative to one chip, defined by locating pinholes in the soldering grid frame, the balls are released into the grid holes by stopping the vacuum and starting $N_2$ flow at a pressure of a few mbar. In the case of the OB the grid frame has a chessboard structure (Fig. 19 bottom) to allow the placement of the same ball transfer tool. A rotation of $180^o$ of the soldering grid allows the access to the second set of chips.
The loading of the balls is presently performed using a small brush to capture and deposit a small amount on the peek plate until all holes have the respective ball. A more sophisticated system is under study, where the balls are bouncing inside a container by gas pressure and vibration and then captured by vacuum. In addition a similar tool for a single ball will be available, thus allowing interventions at level of single hole.
The hole for vacuum and gas has presently a diameter of 6 mm; such a value as well as the type of fittings will be discussed and agreed upon with the contractor during the design stage.

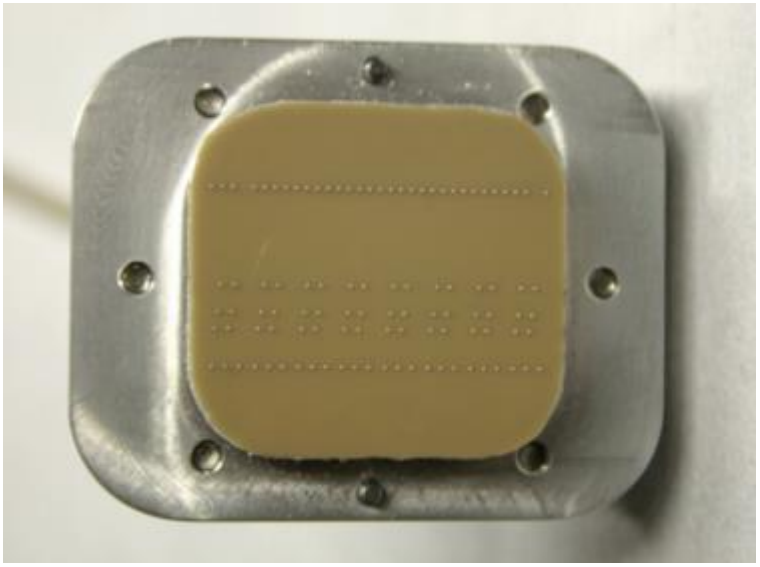


**Fig. 21 A photo of the soldering ball transfer tool prototype loaded with all balls.**

## 3.4 Description of deliverables supplied by the contractor

This section presents a detailed description of some of the items to be included in the supply by the contractor.

***The laser system.***
The laser system to be integrated is described in details in the annexed technical sheets. It is produced by Dr. Mergenthaler GMBH & CO and consists of the laser head LH2501 of 220 mm x 122 mm x 40 mm (weight: 1.2 kg), and the LASCON® Hybrid device, which is a unique combination of infrared temperature measurement, control system and integrated high power diode

laser. The laser head is equipped with a fibre coupled infrared pyrometer and video camera. The camera and the pyrometer are projected coaxial into the laser beam by beam splitters. The beam splitter cube of camera and pyrometer can be mounted also in a 90° version to save space. The LASCON® control software, which runs under Linux or Windows, is also provided to manage the laser soldering process and data storage. The video camera is a USB colour camera with SXGA (1280x1024) resolution. The LASCON® Hybrid is connected via Ethernet to a PC; industrial I/O terminal with 24 V digital and 0-10 V analogue is also available for integration in automation lines and connection to PLC's. The LASCON® control software, which runs under Linux or Windows, is also provided to manage the laser soldering process in closed loop feedback using pyrometer measurements at 10 kHz sampling rate, data visualisation and storage. Data are classified in folders using the chip and FPC serial number, and the sequential number identifying the contact pad. For each soldering the following information is stored: set temperature profile, measured temperature, laser power, video of process.
Fig. 22 shows a picture of the test system supplied by Dr. Mergenthaler GMBH & CO where the laser head is visible.

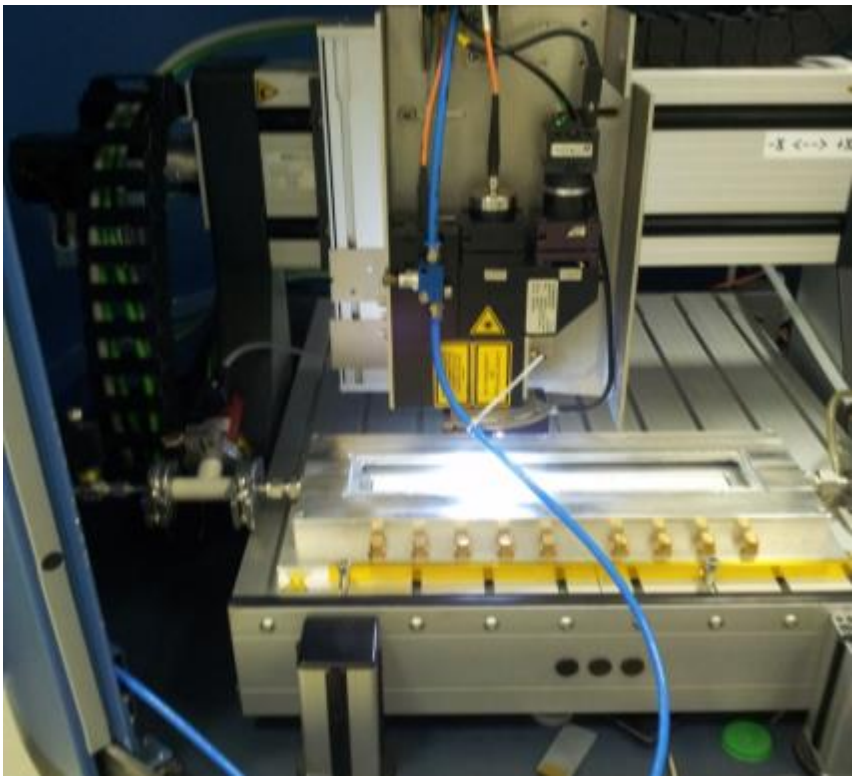


**Fig. 22 A photo of the laser system used for soldering tests.**

For the positioning of the laser beam, which has a diameter of 250 μm in the focal plane, an accuracy of ± 30 μm is required both in X and Y directions. Three different modes of operations shall be implemented for the positioning of the laser head:

a) Fully manual by an operator, using a console, in X, Y and Z directions; this mode is used for testing purposes and laser beam focusing optimization; minimum step shall be better than 10 μm in all directions.
b) Programmable in X,Y, providing X,Y coordinates either as keyboard input for a single position or from a text file with suitable format for multiple positions in sequence.

c) Fully automated, centred in FPC holes recognized by the vision system.

Concerning safety requirements for the usage of the laser, the automatic system is required to be CLASS 1: suitable closing panels (or windows compatible with laser) and interlocks shall be implemented.

***Vacuum and gas system.***
The tooling described in Section 3.3, which will be supplied by CERN, needs various vacuum and $N_2$ gas lines to be implemented and controlled by the HIC automatic assembly systems:

- For the IB assembly table: n. 9 individual lines for the chips vacuum chuck at ~ -200 mbar with respect to ambient pressure; n. 1 line for the soldering volume down to 1 x $10^{-1}$ mbar (it shall be possible to use this line also to purge the volume with N2 at a few mbar pressure and ~ 20 l/h flow);
- For the OB assembly table: n. 14 individual lines for the chips vacuum chuck and n.1 lines for the FPC frame at ~ -200 mbar with respect to ambient pressure; n. 1 line for the soldering volume down to 1 x $10^{-1}$ mbar (it shall be possible to use this line also to purge the volume with N2 at a few mbar pressure and ~ 20 l/h flow);
- For the MFT assembly table: n. 5 individual lines for the chips vacuum chuck at ~ -200 mbar with respect to ambient pressure; n. 1 line for the soldering volume down to 1 x $10^{-1}$ mbar (it shall be possible to use this line also to purge the volume with N2 at a few mbar pressure and ~ 20 l/h flow);
- n. 2 lines for the soldering ball transfer tools (one for multiple and one for single) at ~ -200 mbar with respect to ambient pressure; the same lines shall be connected to $N_2$ at ~2 mbar for the balls release;
- n. 1 line for the chip probe card system vacuum chuck.

One important requirement for the vacuum section connected to the assembly table is that, when starting the vacuum prior to the laser soldering or restoring the atmospheric pressure, a difference in pressure shall always be established between the soldering volume and the chips vacuum chuck to avoid any displacement of the chips. Also vibrations shall be avoided to prevent any displacement of soldering balls.
It is left to the contractor to decide whether separate pumps, for vacuum chuck and for soldering volume, are necessary. Dry vacuum pumps shall be used with speed in the range of 15-20 $m^3$/h.

***Ionizer system.***
An ionizer fan shall be integrated in the system both to ease the handling of the soldering balls and to minimize the risks related to ESD issues. The location of this device shall be agreed during the design phase. This device shall be active during the phases 1, 2 and 3 described in Section 3.2.

***Sensor system.***
The sensor system shall perform the following tasks related to accurate motion and placement of components, and automated optical inspection:

1) <u>Check of chips dimensions, integrity and surface cleanness.</u> The system shall be able to measure the silicon chip dimensions with a precision of ± 5 µm; it shall detect cracks along the edges and dust or particles on the contact pads or on the full surface. Also, the aspect of contact pads (e.g. uniformity of gold layer) could be verified. Fig. 23 shows various

examples of defects to be detected. The complete errors catalogue for chips quality assurance will be prepared later and agreed upon with the contractor during the design stage.

2) Assist the operator in the alignment of chips upon placement on vacuum chuck.
3) Check of soldering ball transfer process. The vision system shall verify whether all balls have been uploaded by the ball transfer tool. After the release of the balls the system shall check the status of all holes and point-out the following faults: a) ball not inside the FPC hole (for example on the hole's edge); b) missing ball; c) more than one ball in the same hole. In this case the operator will intervene on the faulty holes with the single-ball tool. Finally a new check by the vision system shall confirm that the FPC is ready for soldering.
4) Check of soldering joints. Each interconnection will be classified on the basis of process parameters measured by LASCON® (temperature, laser power) in conjunction with high resolution images and profile graphs generated by the vision system. The software for image processing will be developed by CERN and details on data format and implementation will be discussed with the contractor during the design stage.
5) Measurement of chips position with respect to reference pinholes. After HIC assembly vacuum will be stopped and chips released from the vacuum chuck. The HIC will be kept in place and using three reference markers visible through the corresponding inspection openings in the FPC, the position of each chip shall be measured with ± 5 µm resolution. The corresponding data shall be stored together with soldering data for that FPC.

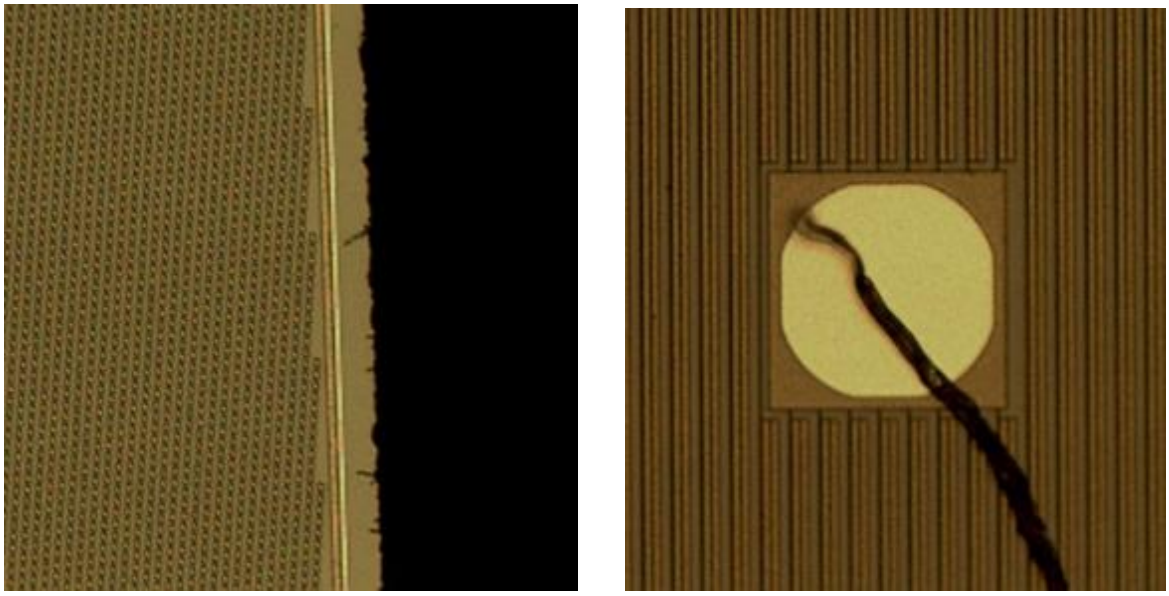


**Fig. 23 (Left) Microscope image of cracks along a silicon chip edge; when the cracks reach the seal ring the chips has to be discarded. (Right) Microscope image of a small fibre on top of a contact pad.**

### 3.5 Requirements on assembly speed

Accuracy in placement and integrity of silicon chips shall be ensured as first requirement. In terms of assembly speed, it is clear that the total time to produce one HIC will be dominated by the various manual operations performed by the operator and especially by the duration of the soldering process. The following time has been assumed for each step of the HIC assembly cycle:

| Phase | Estimated duration [sec] |
|---|---|
| Visual inspection of one chip | 120 |
| Transfer of one chip from pallet to assembly table | 60 |
| FPC/soldering mask placement (operator) | 180 |
| Soldering balls placement for one chip (operator) | 120 |
| Assembly table closing (operator) and vacuum pumping | 600 |
| Laser soldering of one interconnection | 6 |
| Movement of laser head from one hole to next | 3 |
| Measurement of chips positions in HIC | 60 |

The specified timing is a preliminary requirement representing the expected order of magnitude for the speed of each process. The system performance in terms of speed will be discussed and agreed upon with the contractor at the design stage.

Taking into account the above mentioned values, the following cycle time has been estimated for the production of an ITS OB HIC (7x2 chips, 100 contacts/chip) in case of absence of faults detected by the automated optical inspection or more generally by the sensor system:

| Phase | Estimated duration for ITS OB HIC (7x2 chips) [h] |
|---|---|
| Check of chips and placement | 0.7 |
| FPC/soldering mask placement | 0.05 |
| Soldering balls placement | 0.5 |
| Assembly table closing and vacuum pumping | 0.25 |
| Laser soldering | 3.5 |
| Measurement of chips positions in HIC | 0.25 |
| **TOTAL** | 5.25 |

### 3.6 Purchase option tasks

The following additional tasks shall be quoted by the bidders according to the Table 1 presented in Section 3.7 below:

1) Fully automated placement of chips. In this operating mode the silicon chips are sequentially picked up and placed on the vacuum chuck by the machine in a fully automatic way. The same positon accuracy of ± 5 µm at 3σ shall be achieved.

2) Chips electrical test. Electrical testing of chips shall be performed using the needle probe card system supplied by CERN (Fig. 24). In the current design, two needles per contact pad are foreseen (Fig. 25), a solution adopted to verify the establishment of electrical contact on every pad prior to the chip testing. The needles are 80 μm thick with a tip sharpened down to 10 μm and have a pitch of 30 μm; the placement of the probe card on the chip requires an accuracy of ± 20 μm in X,Y, while a finer adjustment in Z is necessary to ensure the electrical contact with the minimum load possible (no force contact). A possible solution is to use the return current circulating in the double needles system as signal to stop the downwards vertical displacement. The details shall be discussed with the contractor. The probe card requires 5 V DC power supply and has Ethernet connection to be interfaced to a Windows PC, where the control software provided by CERN shall be installed.
3) Automatic placement of soldering balls. A fully automated system shall be proposed to transfer the 200 μm diameter soldering balls from a suitable tray into the holes of the FPC through the soldering mask. Since the balls are coated with a thin protective film, any friction or scratching shall be avoided or minimized.
4) Quality control by vision system. Quality checks of interconnection soldering joints shall be implemented in the vision system in order to classify them using a colour code (e.g. green, orange, red) or a noun (e.g. good, review, bad) on the basis of Sn/Ag aspect (colour and shape) and 1D profile. Fig. 26 shows various examples of soldering joints. The complete catalogue of errors will be discussed with contractor.

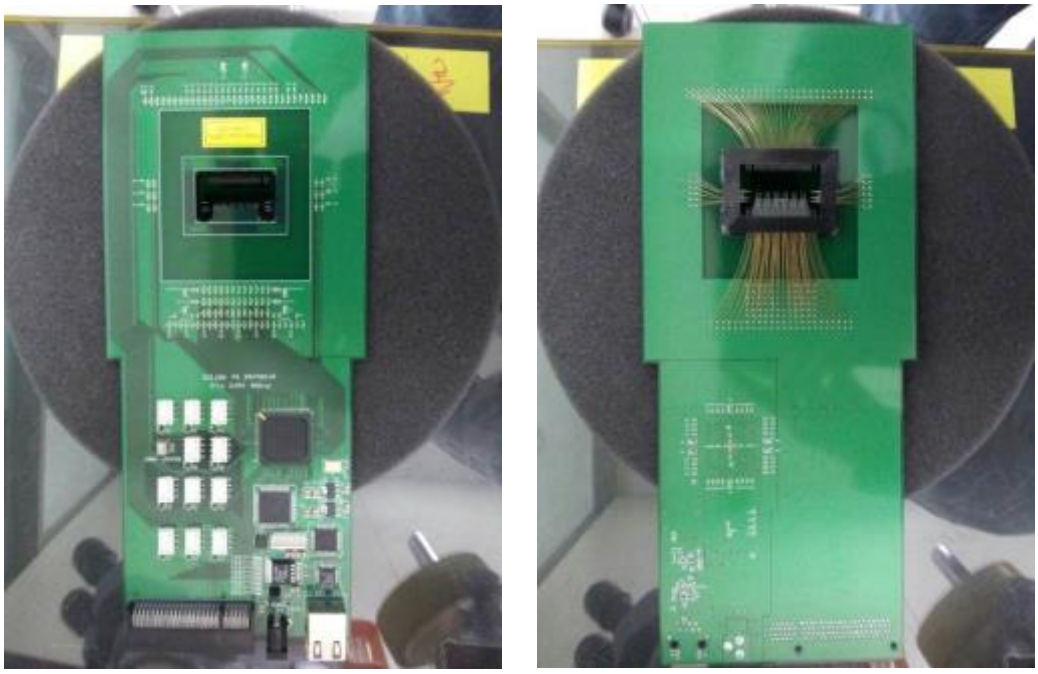


**Fig. 24 Top (left) and bottom (right) views of a prototype of the needle probe card.**

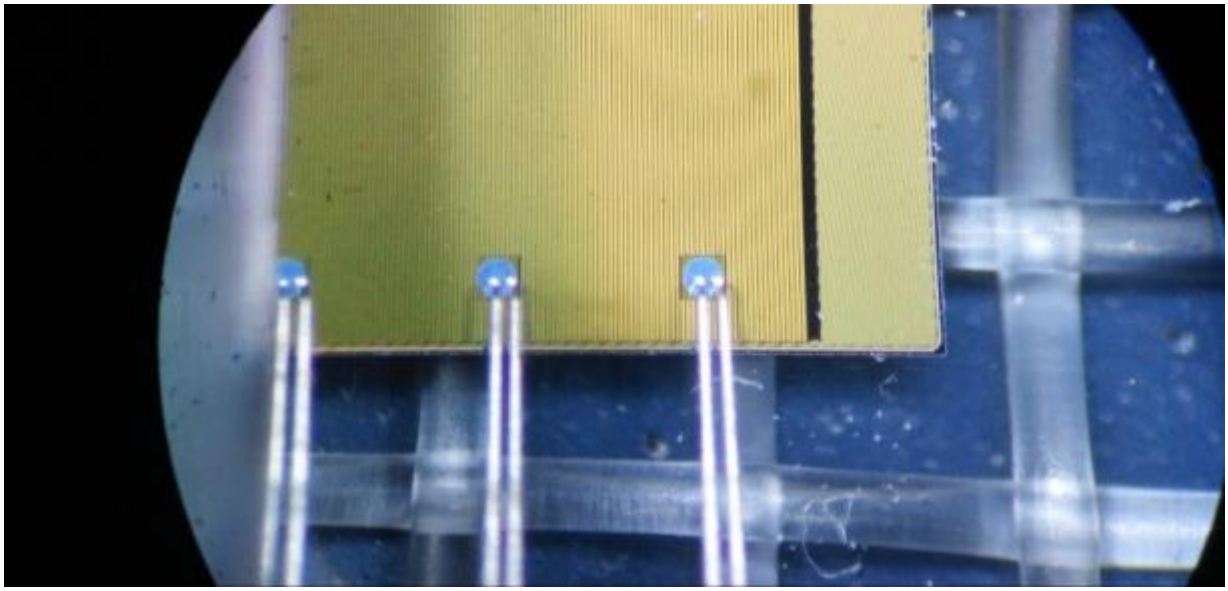


**Fig. 25 Microscope photograph of the two needles touching the contact pads on a chip.**

## 3.7 Summary of systems and options to be quoted

| | |
|---|---|
| **Baseline system for contract adjudication** | Price for one prototype to be installed at CERN French site in Meyrin + 3 systems to be installed in Italy (Bari), France (Strasbourg) and South Korea (Pusan) |
| **Purchasing option 1: additional amount of systems** | Up to three systems to be installed in UK (Liverpool), China (Wuhan) and USA (Berkeley, CA) |
| **Purchasing option 2: automatic placement of silicon chips in addition to semi-automatic mode** | Additional unit price |
| **Purchasing option 3: chip testing with probe card** | Additional price for implementation in prototype and one system |
| **Purchasing option 4: automatic placement of soldering balls** | Additional unit price |
| **Purchasing option 4: Solder joint inspection by vision system** | Additional unit price |

**Table 1 – Summary table for the various configurations, options and quantities to be quoted.**

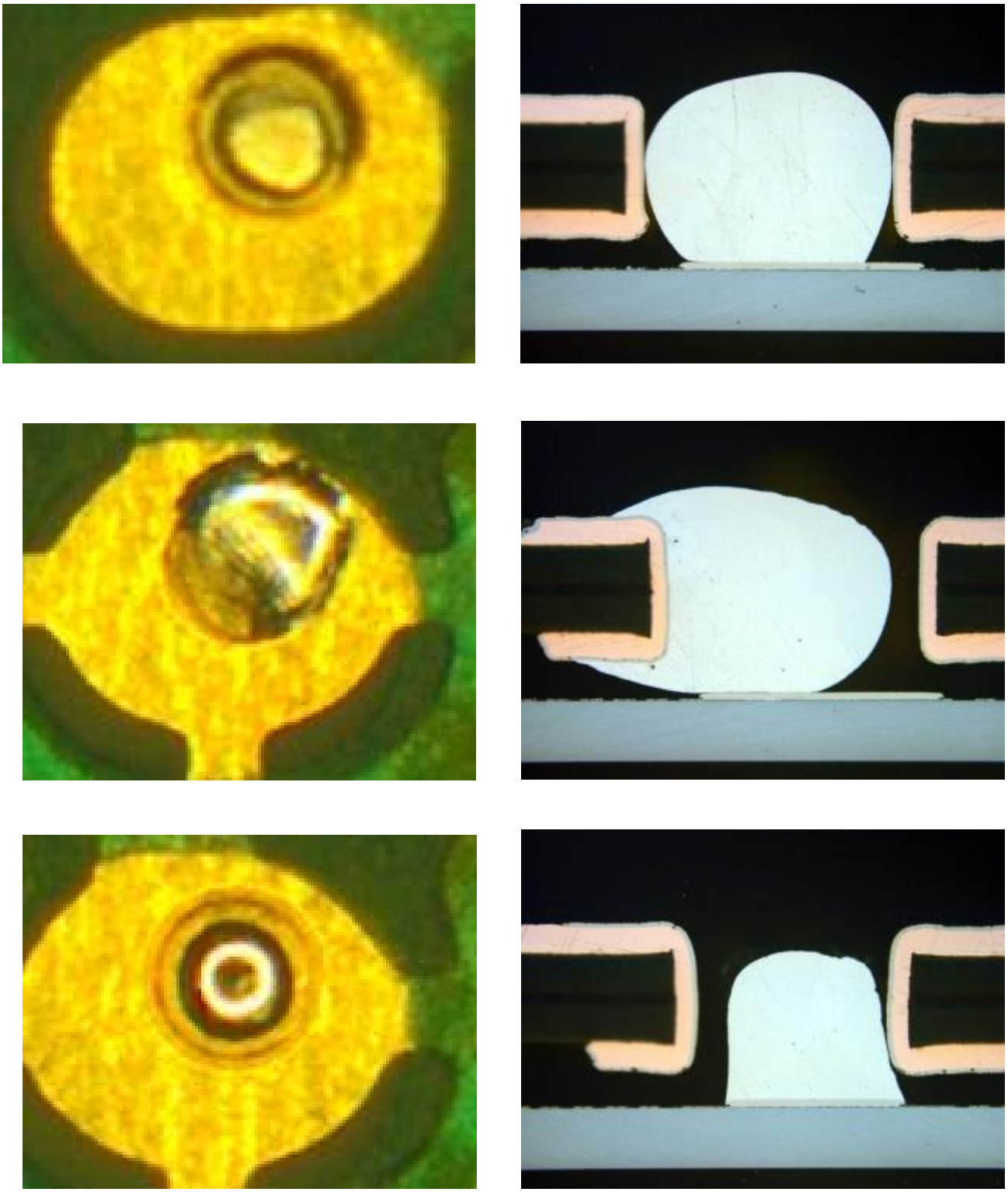
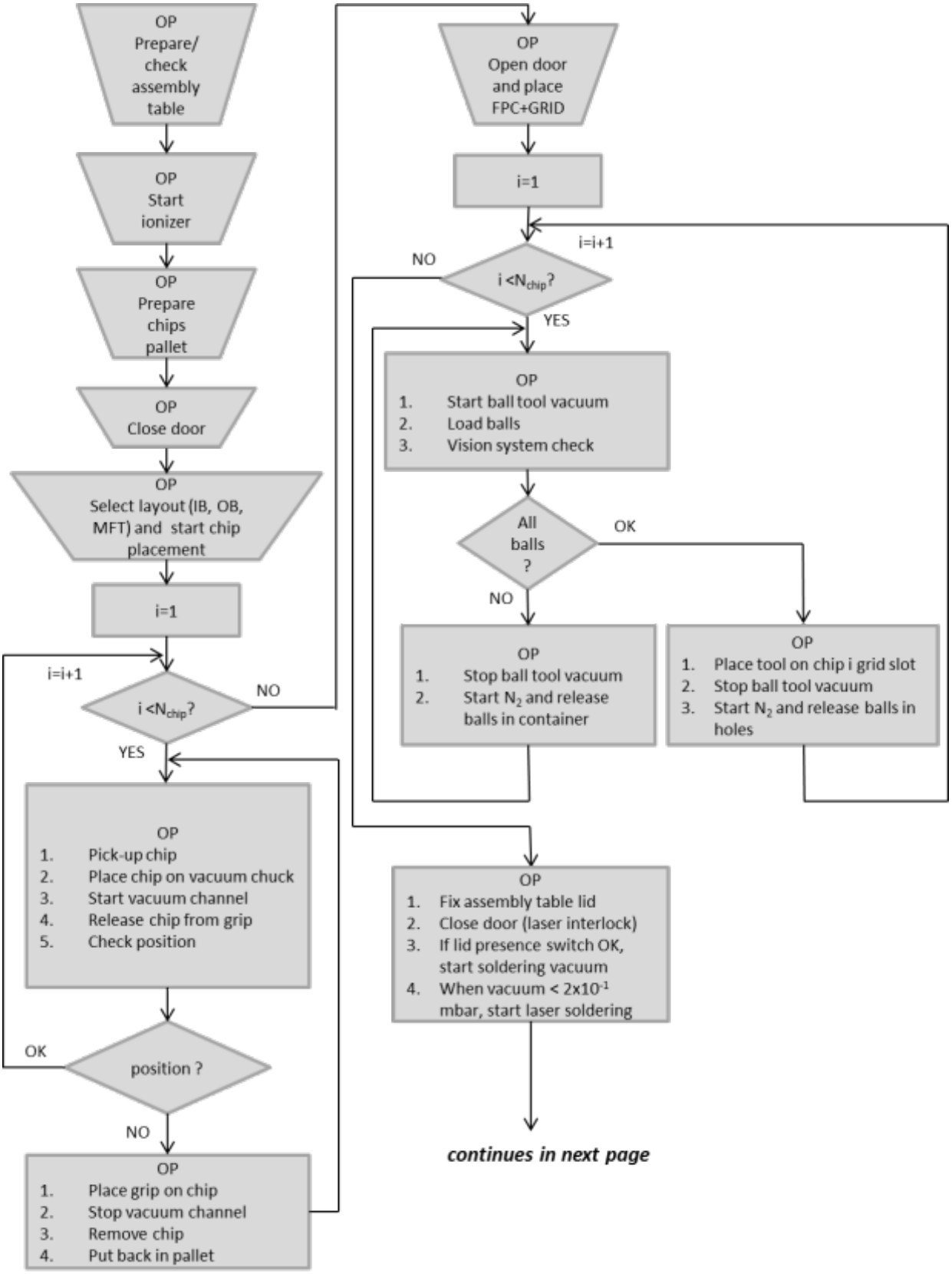


**Fig. 26 Microscope photographs of three examples of soldering joints which are considered not acceptable. The top view is shown on the left, while the cross section of the corresponding interconnection is shown on the right.**

## 3.8 Preliminary procedure flow-chart

The following flow-chart summarizes to various steps of the baseline full assembly procedure.

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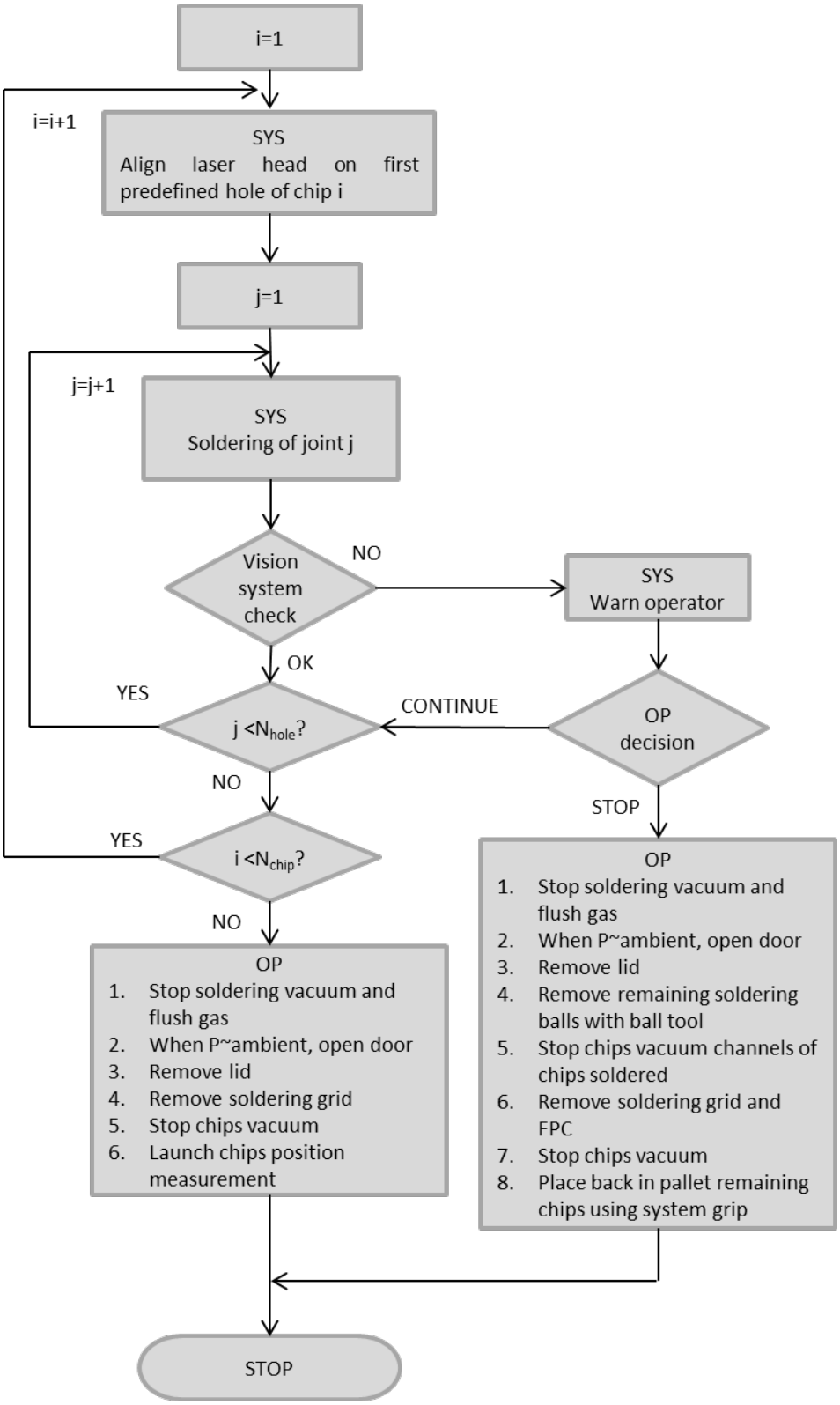


The procedure illustrated by this flow-chart should be considered as preliminary and does not include the quality assurance inspection of chips prior to soldering; the details of the various steps will be discussed and agreed upon with the contractor at the design stage.

## 3.9 Applicable Standards, Rules and Regulations

The supply shall comply with all relevant professional and CERN standards and codes including, but not limited to:

- DIN EN 61340 – 5

## 3.10 Performance Requirements

The supply shall comply with the following requirements in terms of performance:

- Mean Time Between Failures (MTBF): 2000 h.

## 3.11 Safety Design Requirements

The supply shall comply with CERN safety rules (available at the link: http://cern.ch/safety-rules ) and of the Swiss and/or French and European legislation.

In particular:

- CERN safety Code C1 for electrical equipment
- CERN safety Code IS22 for the usage of lasers
- CERN safety Code IS23 and IS41 for specifications on insulation materials for cables
- Machinery Directive 2006/42/EC

## 3.12 Environmental Conditions

The conditions of the environment that the supply will operate in, for example the ambient temperature and the relative humidity, will be discussed and agreed with the contractor.

## 3.13 Information and Documentation

### *3.13.1 Detailed Design File*

The contractor shall submit to CERN for approval, within 8 weeks after the start of the contract, a detailed design file of the full system. Any delay in the submission of such design file will be subject to penalties as specified in the *General Conditions of CERN Contracts*.

### *3.13.2 Documentation Handling, Quality Control and Quality Assurance*

The contractor shall plan, establish, implement and adhere to a documented quality assurance program that fulfils all the requirements described in this technical specification.

In addition to the requirements of section 3, the contractor may propose any internationally recognised design standard, subject to prior written approval by CERN. The contractor shall state his intended method of design including applicable codes as part of his bid. CERN reserves the right to veto the use of certain codes or norms if it is considered that their application will not ensure compliance with this technical specification.

The contractor shall submit all documents produced in electronic format:

- Drawings in CATIA®, AUTOCAD® and/or HP-GL® format;
- Text documents in Microsoft Word® and PDF® format;
- Cost breakdowns and equipment lists in Microsoft Excel® format;
- Schedule in Microsoft Project® format.

The contractor shall comply with professional and/or CERN's standards/codes in matters of document editing, design/drawing process, design reviews and approval, naming conventions and tagging, quality assurance/control.

# 4. PERFORMANCE OF THE CONTRACT

All deliverables and activities that are not explicitly mentioned in the technical specification but are essential for the execution of the contract shall be considered an integral part of the technical specification and therefore subject to clause 3.1 of *General Conditions of CERN Contracts*.

## 4.1 Delivery, installation and commissioning schedule

Once the contractor is notified of the award of the contract, he shall deliver the supply according to the following delivery schedule:

- Delivery to the CERN French site in Meyrin of prototype system within 6 months from date of notification of the contract;
- Delivery to the above mentioned assembly sites of the remaining systems (three, up to a maximum of six) within 12 months from the acceptance of the prototype system. The detailed schedule for the delivery to the various assembly sites other than CERN will be discussed and agreed upon with the contractor.

At the beginning of the contract and before the start of material procurement, the contractor shall submit for CERN's approval a detailed schedule defining the processes and methods, which he intends to implement. After discussion and agreement with CERN, the contractor shall supply, within one month from the start of the contract, a written programme detailing the manufacturing and intermediate testing schedules to validate design of the relevant sub-systems during the prototyping phase. The programme shall include preliminary dates for inspections and tests.
CERN and its representatives shall have free access during normal working hours to the manufacturing or assembly sites, including any subcontractor's premises, during the contract period.

The schedule shall make provision for CERN's official holidays and take into account other conditions related to the execution of the contract.

### *4.1.1 Particular invoicing features of the delivery to the various sites*

The invoicing of the prototype system delivered to the CERN French site in Meyrin shall be VAT free as indicated in the Tender Form.

The invoicing of the series production systems delivered to all other sites shall be subject to specific national rules.

## 4.2 Working on the CERN Site

### *4.2.1 General Safety Requirements*

The term "Safety" includes safety, occupational health, working conditions and environmental protection.

Any contractor working on the CERN site shall take into account and implement the rules and provisions defined in document reference PSO/2011-001/Rev.5 entitled *Working on the CERN Site*:

The work of contractors on the CERN site is subject to the following Safety regulations:

http://edms.cern.ch/document/1155899/5.0

It is suggested consulting also the Safety Guideline document which addresses most of the questions related to working on the CERN site:

http://edms.cern.ch/document/1334815/4.0

Moreover, any contractor shall inform, in writing, his employees concerned and his potential sub-contractors of the applicable law. He must also take the necessary measures so that his sub-contractors also inform their employees concerned of the applicable law.
The activities performed by the contractor shall be performed on the French part only of the CERN site.

The contractor shall take note of the above-mentioned agreements and the resulting obligations for contractors and their sub-contractors (see section 1.3 of the document *Working on the CERN site*).

The activities/part of the activities performed by the contractor on the CERN site will be classified as a "Category 2" activity; CERN will prepare, with the collaboration of the contractor, a Prevention Plan (PdP), summarizing the main general safety issues to be followed before and during the works.

Before the beginning of the work, the contractor shall:

- Collaborate with CERN to establish the PdP, providing a work description with presentation of the activities to be carried out, the workers involved in those activities, an assessment of the risks inherent in the worksite and the risks generated by activity, the preventive and protection measures to be taken for each risk;
- Take part in all joint inspections.

During the performance of the contract, the PdP shall be updated as the risks evolve and at least annually. The contractor shall inform CERN of changes in the potential risks as and when they arise and vice versa. Some activities are subject to a notice of starting work issued by CERN (AOC or Impact).

#### *4.2.2 Specific Safety Requirements*

For the installation in sites other than CERN the contractor shall refer to national safety regulations of each specific country which will be provided upon contract adjudication.

### 4.3 Tests

#### *4.3.1 Tests Carried Out at the contractor's Premises*

CERN reserves the right to be present, or to be represented by an organization of its choice, to witness any tests carried out at the contractor's or his subcontractors' premises. The contractor shall give at least 10 working days' notice of the proposed date of any such tests. A preliminary list of tests concerning the described baseline system is reported in the following table:

| Keywords | Test |
|---|---|
| Chips warp, handling | Test of vacuum grip: picking up of chips from pallet, chip integrity, chip flatness while on grip |
| Chips vacuum chuck | Test of vacuum chuck: correct transfer of chips on the vacuum chuck by the grip, switching of vacuum channels, stability of position, chips integrity, chips flatness on chuck |
| Chips placement accuracy ±5 μm at 3 σ | Accuracy of placement on vacuum chuck upon full procedure to transfer chips from pallet to assembly table |
| Vacuum and gas systems for tools and soldering | Loading of ball transfer tool, release of balls, flushing of soldering volume with gas, vacuum of soldering volume, switching of various channels |
| Laser soldering | Automatic recognition of soldering grid hole and centring of laser head, control of soldering process, data storage |
| Sensor system | Each of the task described in Section 3.4, to be defined |

**Table 1 – Preliminary list of the various tests to be performed at the contractor's premises**

A final and more detailed list of tests and related procedures shall be discussed and agreed between CERN and the contractor upon design approval. After the final fabrication acceptance test at the contractor's premises a written document will be prepared describing the process to be used for the HIC assembly.

## 4.4 Contract Follow-Up and Progress Monitoring

The contractor shall assign a person responsible for the technical execution of the contract and its follow-up throughout the duration of the contract. He/she shall be able to communicate in one of the official languages of CERN (English or French).
The contractor shall send a written progress report to CERN every two weeks until completion of the contract. All communications and documents shall be in English or French.

This report shall include all the necessary information, in particular:

- Actual progress in comparison to scheduled progress;
- Updates of Safety documents.

## 4.5 Packing and Shipping

The contractor shall be responsible for the packing and, where specified by CERN (see tender form document), for the transport to CERN and all other sites specified in Section 2.1. In all cases, he

shall ensure that the equipment is delivered without damage and any possible deterioration in performance due to transport conditions.

The contractor shall comply with professional and CERN's regulations in matter of packing and shipping.

### 4.6 Installation and Commissioning

Upon installation of the supply in all assembly sites full commissioning, including assembly of various HICs, shall be performed. A detailed test report shall be prepared by the contractor summarizing the main results of the tests and the procedure to be followed for production.

### 4.7 Acceptance and Warranty

Acceptance of the supply shall be given by CERN only after the commissioned supply is deemed to be in conformity with the contract including documentation referred to in this technical specification, all tests specified have been successfully completed and all tests or other certificates have been submitted to CERN.

The warranty shall be as defined in the tender form. Time and conditions for interventions in case of warranty repairs are defined in the next Section 4.8.

### 4.8 Maintenance

The preventive and/or corrective maintenance shall be provided according to the provisions below.

#### *4.8.1 Preventive Maintenance*

A plan of preventive maintenance during the required three years warranty period shall be established by the contractor prior to system installation in the various assembly sites.

#### *4.8.2 Corrective Maintenance*

The Mean Time To Repair (MTTR) in case of corrective maintenance during the required three years warranty period is: up to five working days for assembly sites in the EU, up to eight days for sites outside the EU.

## 5. CERN CONTACT PERSONS

Persons to be contacted for technical matters:

| Name/Department/Group | Telephone | Email |
|---|---|---|
| Mr Antonello Di Mauro | Tel: +41 22 767 6612 | Antonio.Di.Mauro@cern.ch |
| In case of absence: | | |
| Mr Vito Manzari | Tel: +41 22 767 4676 | Vito.Manzari@cern.ch |

Persons to be contacted for commercial matters:

| Name/Department/Group | Telephone | Email |
|---|---|---|
| Mr Laszlo Abel | Tel: +41 22 767 9561 | Laszlo.Abel@cern.ch |
| In case of absence: | | |
| Mr Dante Gregorio | Tel: +41 22 767 6335 | Dante.Gregorio@cern.ch |

## 6. ANNEXES

- The Tender Form
- The Technical Annex to the Tender Form
- Data sheet (Folder_LH501.pdf) and description of laser system (Folder_LASCON_Hybrid.pdf)
- CERN safety Code C1 for electrical equipment
- CERN safety Code IS22 for the usage of lasers
- CERN safety Code IS23 and IS41
- Working on the CERN site (EDMS 1155899 v.5)
- Safety Guideline (EDMS 1334815 v.4)