OB Stave: highlights from PRR preparation

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ALICE ITS Upgrade

Plenary Meeting

CERN, 2 May 2017

Outline

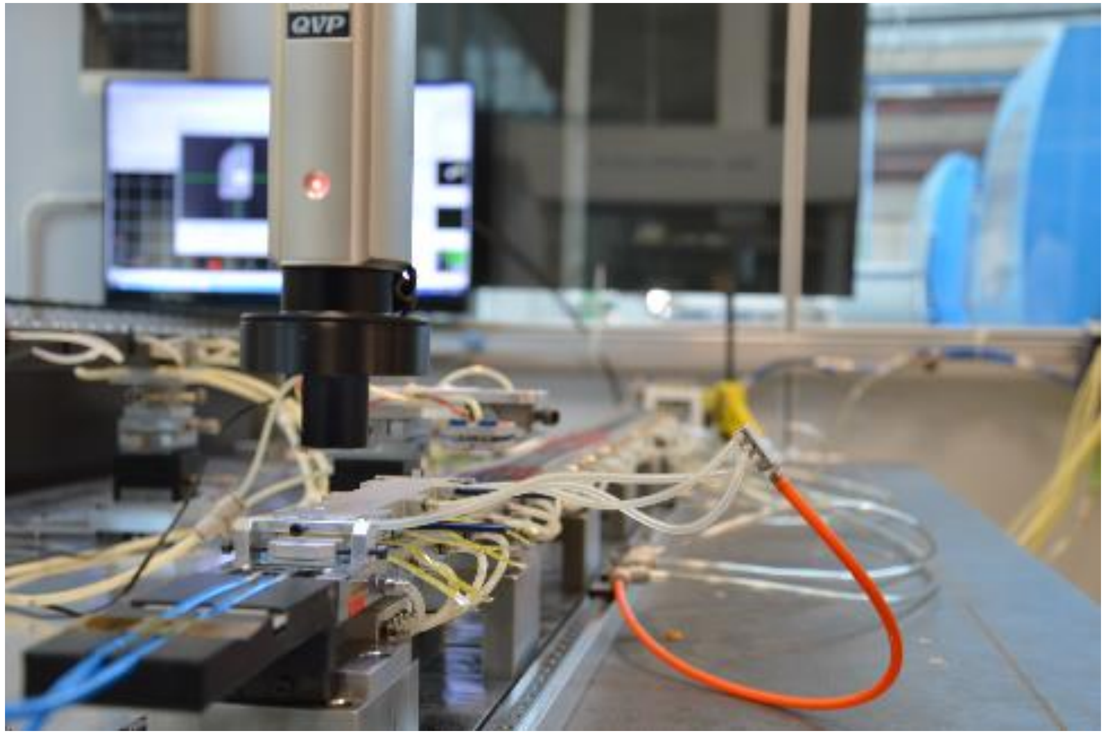
1. Introduction
2. Assembly procedure and tooling
3. Prototypes construction and geometrical survey
4. Test set-up
5. Results of tests on functional prototype
6. Construction Organization and workflow
7. Preparation of the construction sites
8. Packaging and Shipping

Assembly procedure - Introduction

This presentation describes the assembly procedure and the tooling developed for the construction of the OB Stave

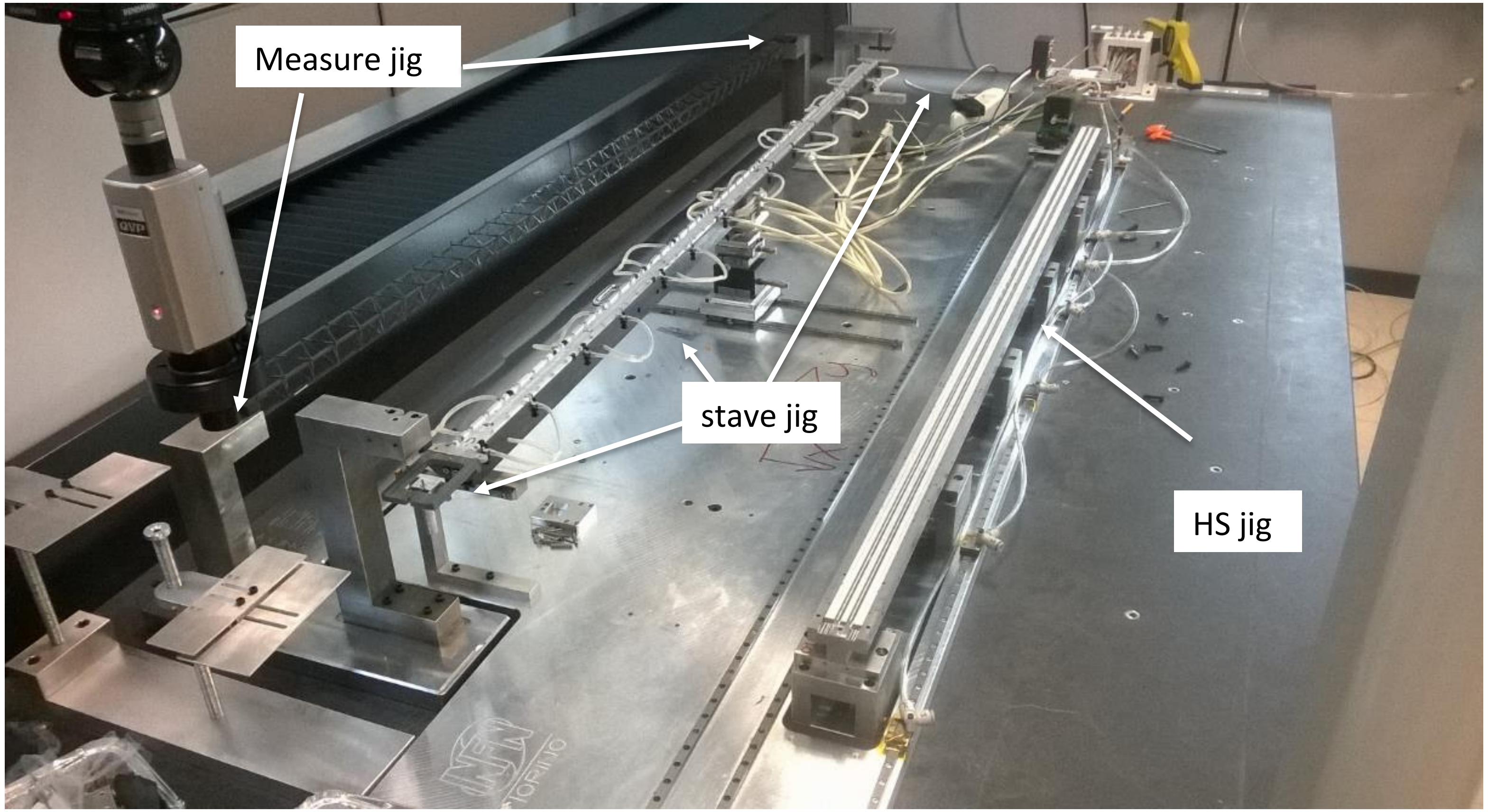
Tooling:

- All the tooling described in the following are conceived to prevent the damage of the 100 µm thick silicon chips
- Manufacturing aims to achieve a planarity and parallelism of the most critical jig surfaces, namely the HS base, 150cm long, within 100 µm
- Tooling and procedure were conceived to guarantee an accuracy of positioning within 100 µm for HICs on HS and within 150 µm for HS on Stave



Assembly procedure - Jigs

1. The HS jig: used for the module positioning and gluing on the CP
2. The Stave jig: used for the HS alignment and gluing to the Space Frame
3. The Measure jig: used for the final Stave metrological survey



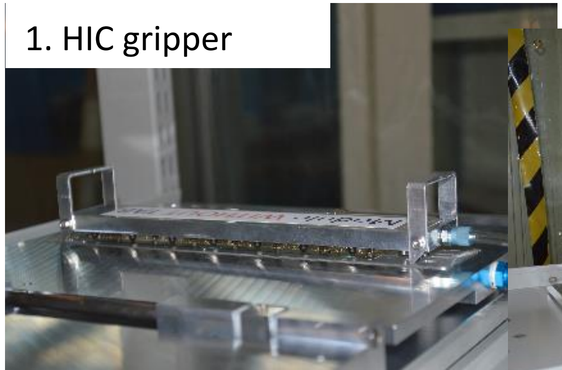
Assembly procedure – TAB cut

TAB

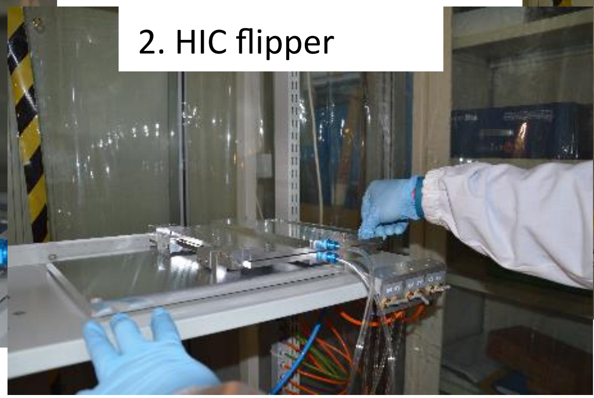
The FPC TAB, used for HIC test, must be cut before the HIC assembly on the CP

This is done with the silicon backplane face up. The HIC is placed on a dedicated tool called FLIPPER by means of vacuum based grippers

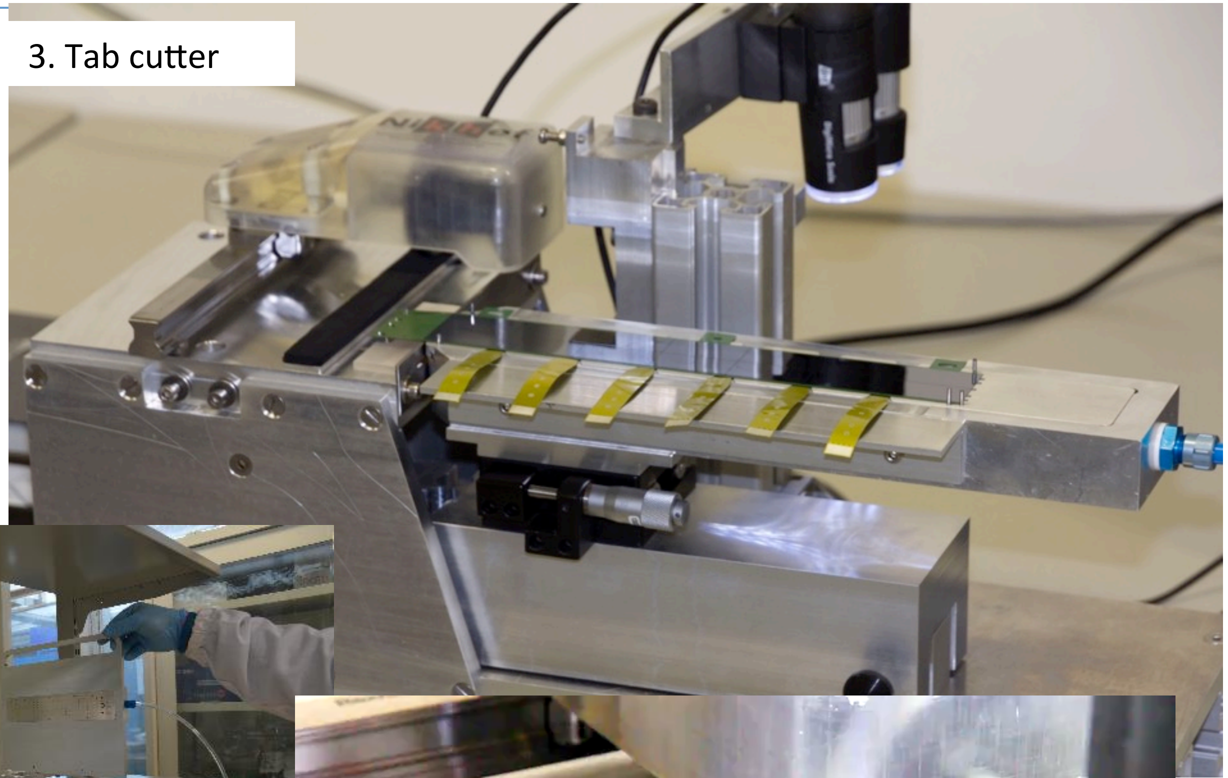
1. HIC gripper

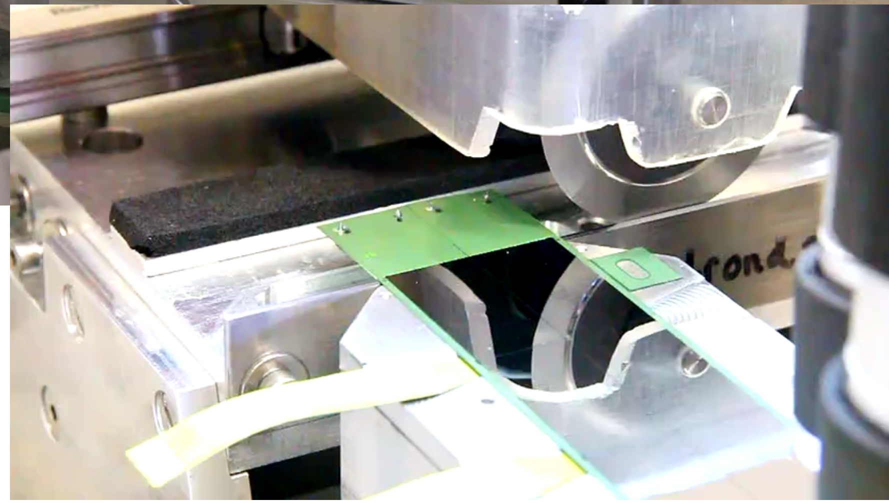


2. HIC flipper



3. Tab cutter



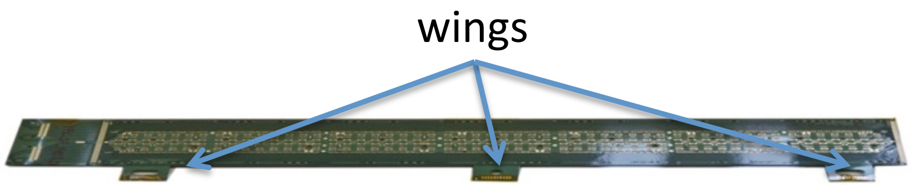


The HIC is then placed on a machine called TAB CUTTER which allows alignment of the HIC with a precision of 10 μm by means of video-cameras placed on the cut line.

The HIC is kept in position by means of vacuum, sucking it from the FPC side. The vacuum chuck was modeled to avoid damaging the wire bonds.

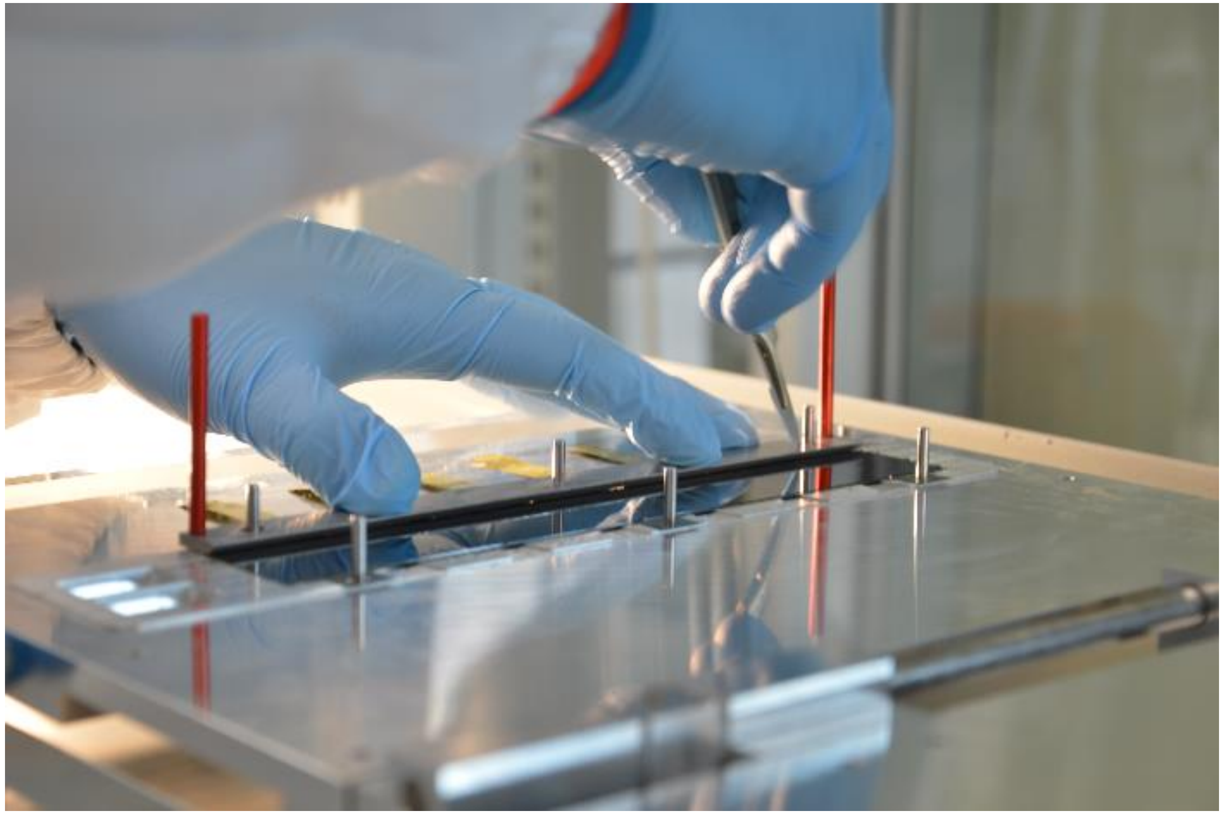
So far more than 15 HICs were cut. Only 1 was damaged during the cut.

Assembly procedure – Wings cut



The FPC wings, used for FPC alignment during FPC construction, must be cut before the HIC assembly on the CP

This is done with the silicon backplane face up after TAB cutting



The HIC is placed on the FLIPPER and kept in position by vacuum sucking it from the FPC side. The vacuum chuck was modeled to avoid damaging the wire bonds.

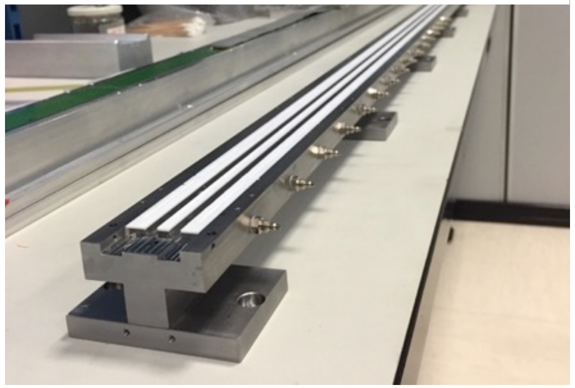
The wings are cut manually using a blade guided by a special tool with narrow slits

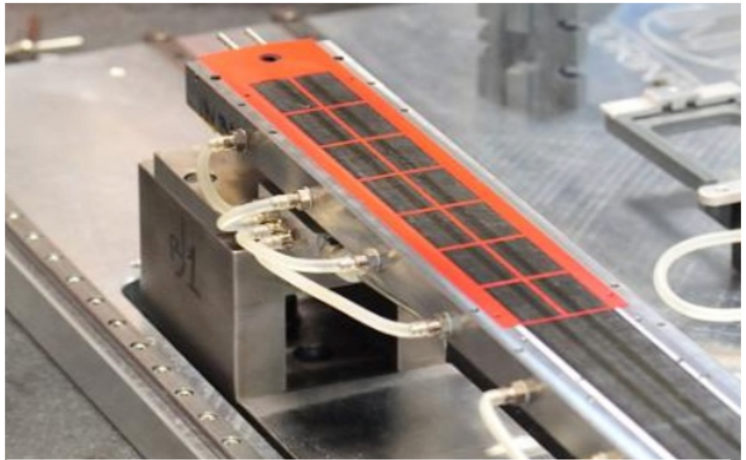
No damage occurred to any of the 15 HICs cut so far.

Nevertheless this operation is rather delicate and the tool needs to be further optimized

Assembly procedure – HIC alignment and gluing

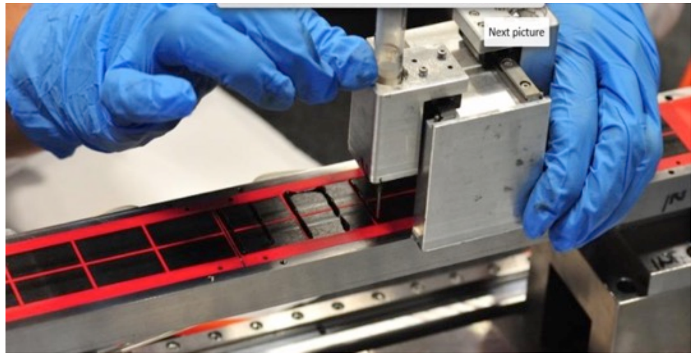
1. CP positioning on the HS base



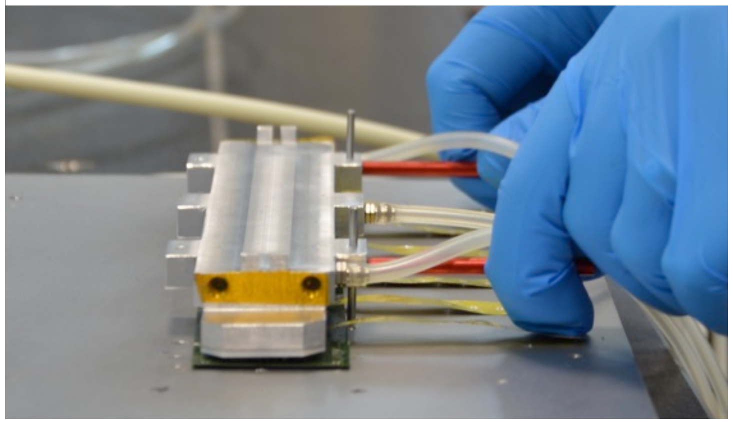


2. Glue mask on the CP

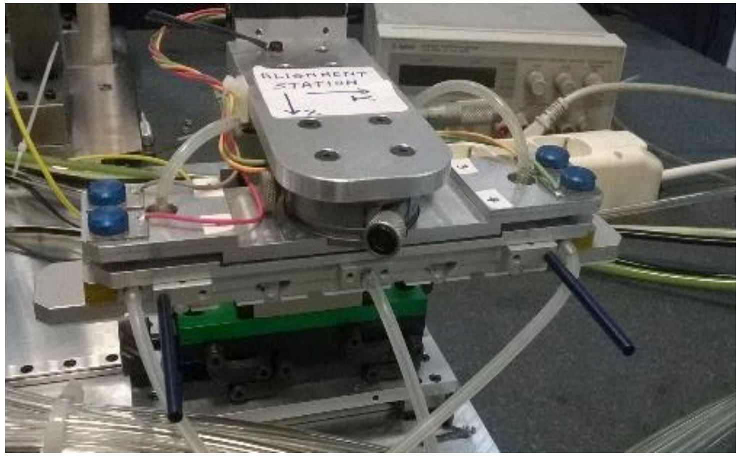
3. Glue spread on the CP

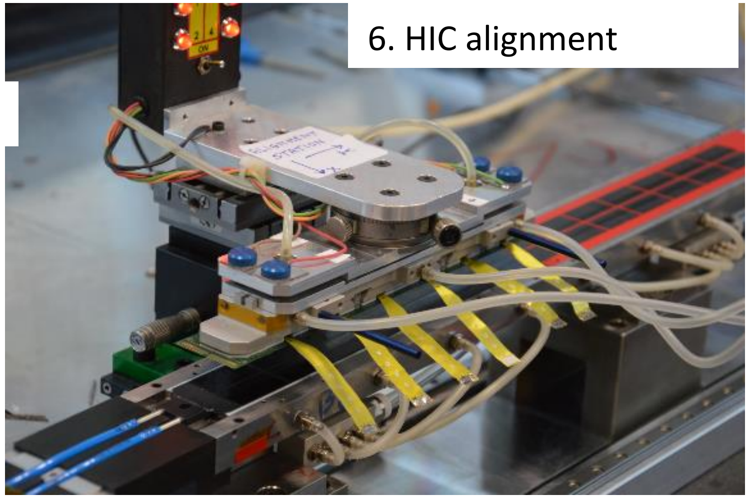


4. HIC gripped by the HIC gripper



5. HIC gripper fixed to the Alignment station





6. HIC alignment

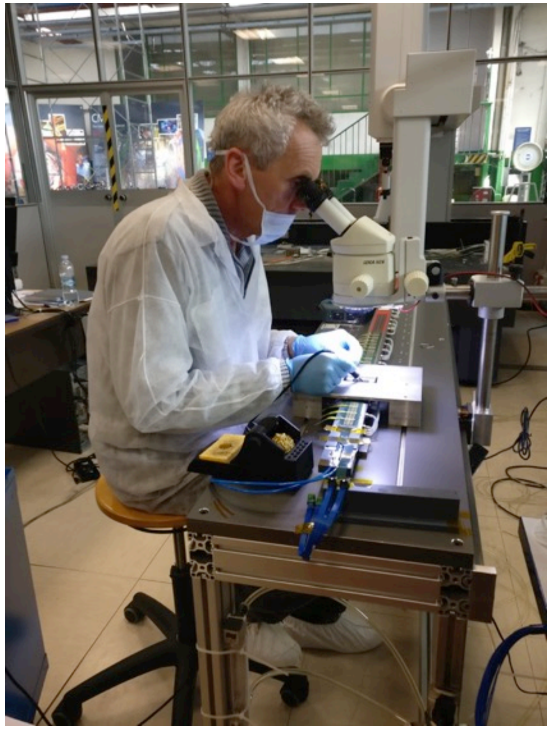
The procedure is described in detail in the Stave assembly slides presented during the EDR:
https://indico.cern.ch/event/518710/contributions/1198926/attachments/1262350/1876019/OB_Stave_assembly_final.pptx

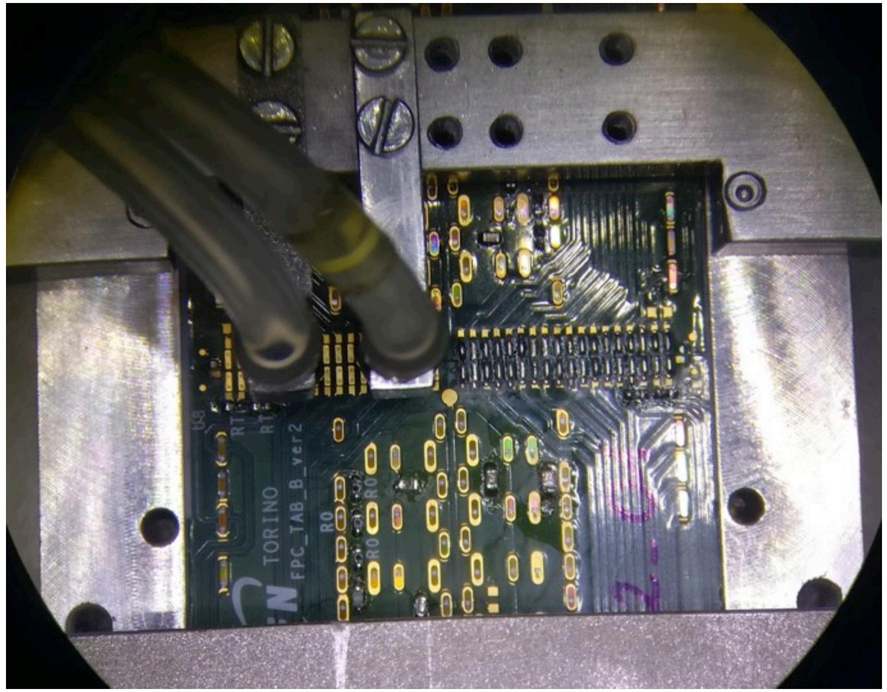
Assembly procedure – HIC to HIC interconnections

HIC to HIC interconnections on CLK, CTRL and DATA lines are made by means of Flex Bridges tin soldered to the corresponding pads on the FPCs

Pads width and pitch: 400μm

36x2 solder points are present at each HIC-to-HIC interconnection



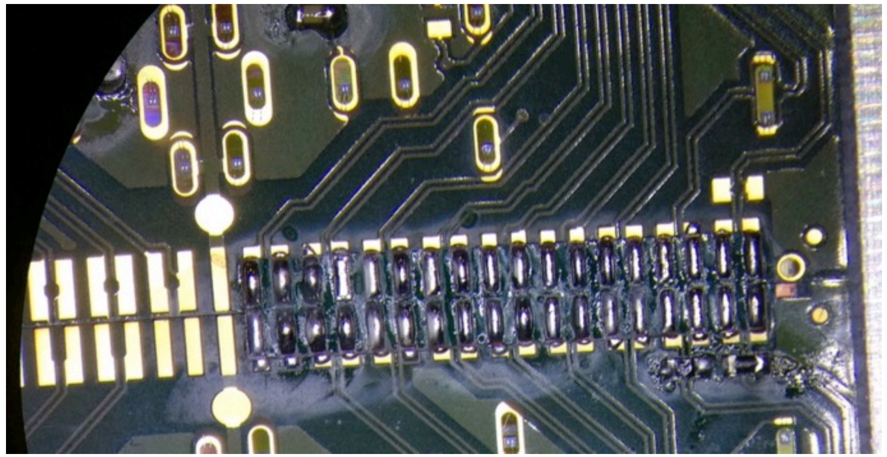


The Soldering table is used for:

- HIC-to-HIC interconnection
- HS electric test

Equipped with:

- microscope
- vacuum tools for precision bridge positioning
- special bases to protect wire bonds



The soldering procedure was testes on dedicated test structure produced with FPCs

These tests allowed us choosing the best tools and tin type to obtain 100% yield

The procedure was successfully followed during Stave 0 assembly

All the connections were good and no damage to the chips or bonds was observed

Stave Assembly – Metrology

METROLOGIC SURVEY:

① MECHANICAL COMPONENTS

② STAVE 0 PROTOTYPE: ALIGNMENT RESULTS

ALIGNMENT TOLERANCES

Requirements for detector alignment based on tracks:

Tolerance on the position of sensors in space < 500 μm

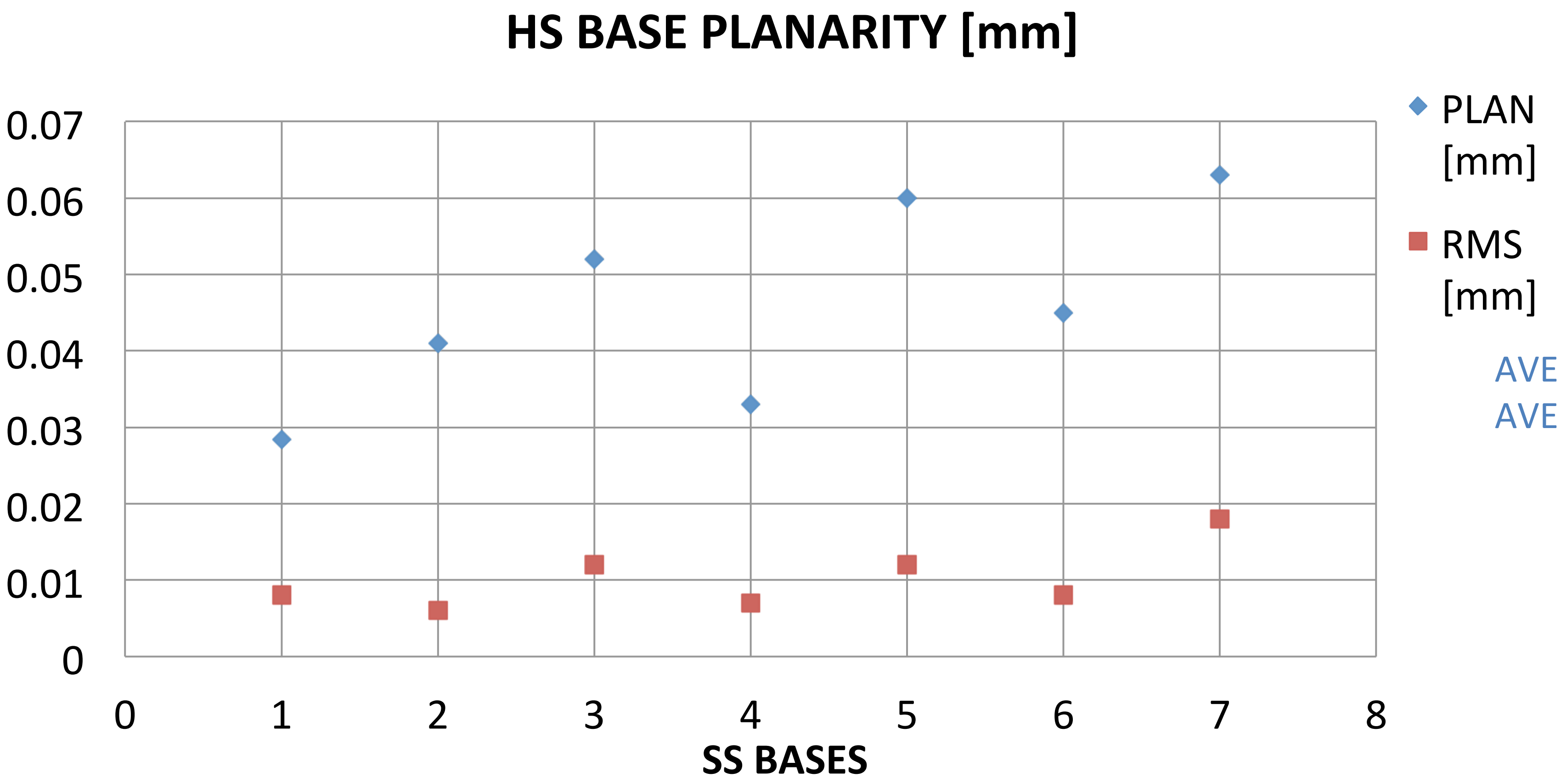
Precision of initial detector alignment (by construction and metrology) < 200 μm

Stave Metrology – HS BASE

The planarity of the HS base is particularly critical because the Base is the support of the CP during the assembly

SEL srl company was chosen to produce the HS bases. The results of the metrological survey show that the HS bases are within the tolerance requested (70μm along 150cm)

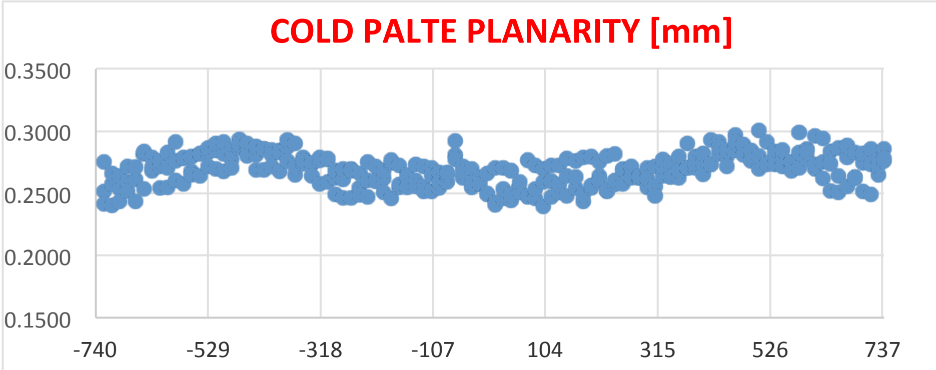
The planarity of the each HS Base produced was measured using the CMM



AVERAGE PLANARITY [mm] <0.05
AVERAGE RMS [mm]~0.010

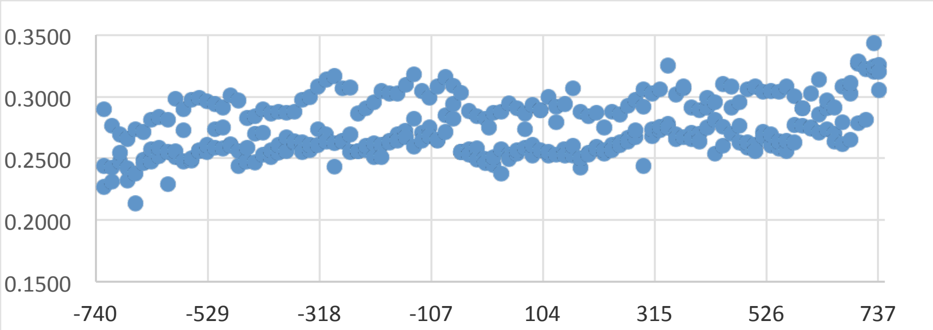
Stave Metrology – Cold Plate Planarity

The planarity of the CP on the sensor side is critical to guarantee an overall precision of sensor position along the z coordinate
Special production procedures were developed to satisfy this requirement (see C. Gargiulo's talk)
The planarity of each CP is measured and stored in the construction DB



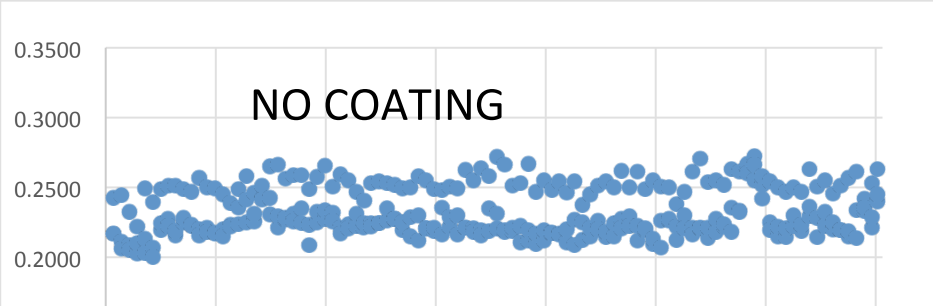
ALC0312_01_031
PLANARITY [mm]: 0.061
AVERAGE THICKNESS [mm]: 0.269
RMS [mm]: 0.013

Used for stave 0 HS left



ALC0312_01_014
PLANARITY [mm]: 0.117
AVERAGE THICKNESS [mm]: 0.274
RMS [mm]: 0.021

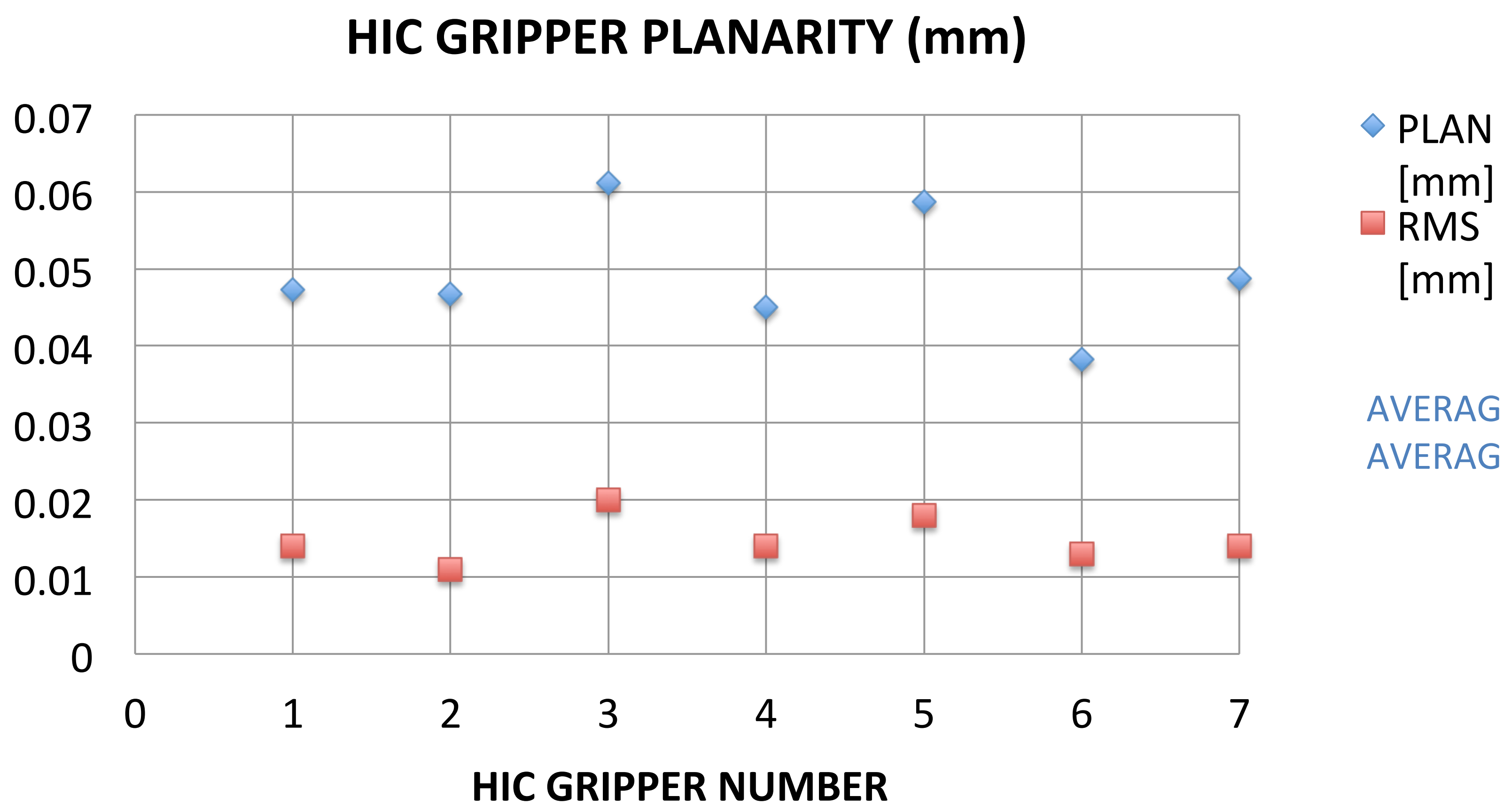
Used for stave 0 HS right



ALC0312_01_048
PLANARITY [mm]: 0.079
AVERAGE THICKNESS [mm]:0.233
RMS [mm]: 0.017

Stave Metrology – HIC grippers

The planarity of the each gripper was measured using the CMM

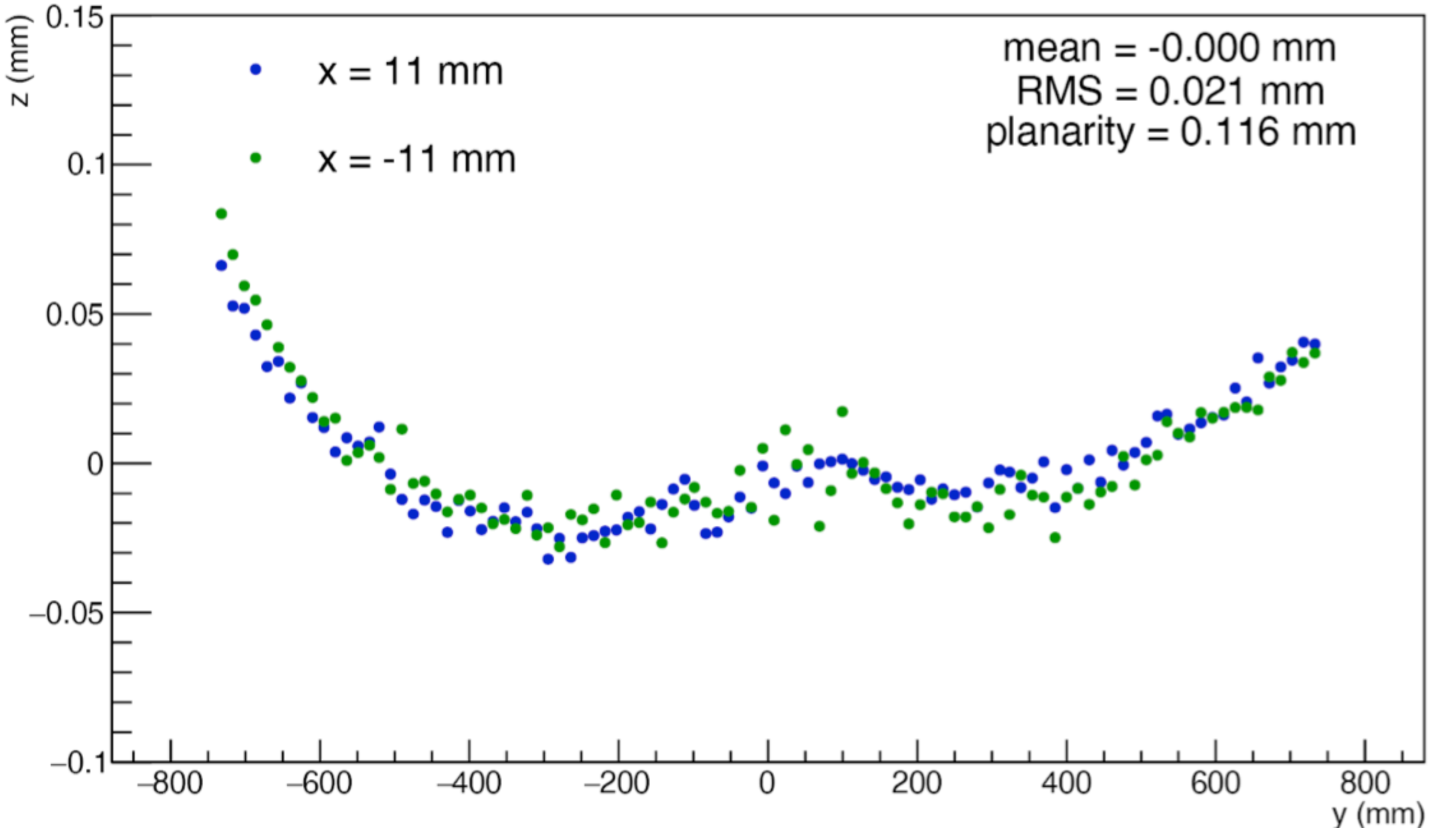


AVERAGE PLANARITY [mm] <0.05
AVERAGE RMS [mm]~0.015

Stave Metrology – HANDLING BAR

The planarity of the HB is critical because it allows keeping the HS flat during Stave assembly.

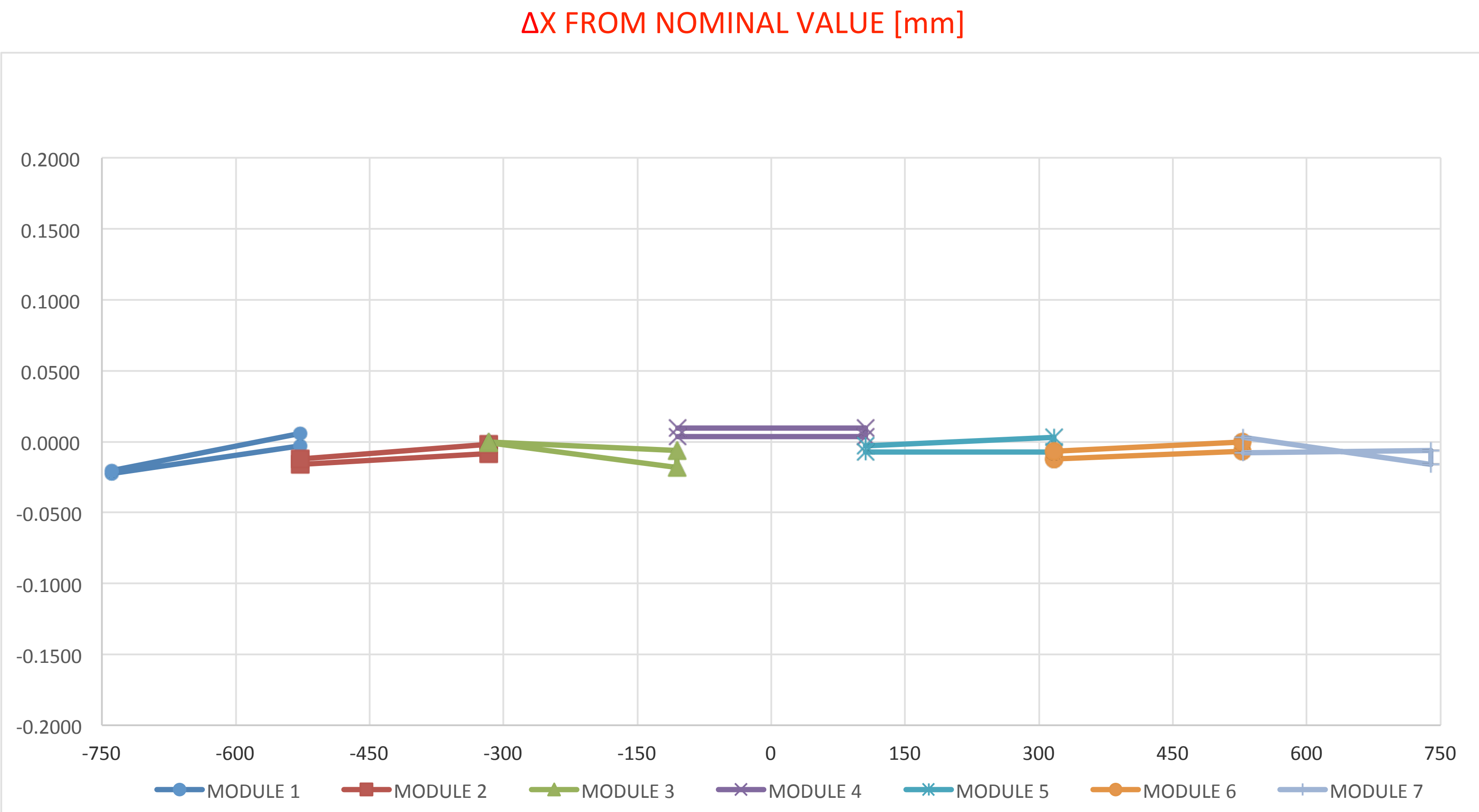
The planarity of the HB was measured using the CMM. Results are within the design goal of 150μm



PLANARITY [mm] = 0.116
RMS [mm]=0.021

Stave Metrology – STAVE 0 - HS0_L

For each HIC the position of reference marker on the 4 corners was measured after each HS assembly
We report the deviations from the nominal position along x coordinate

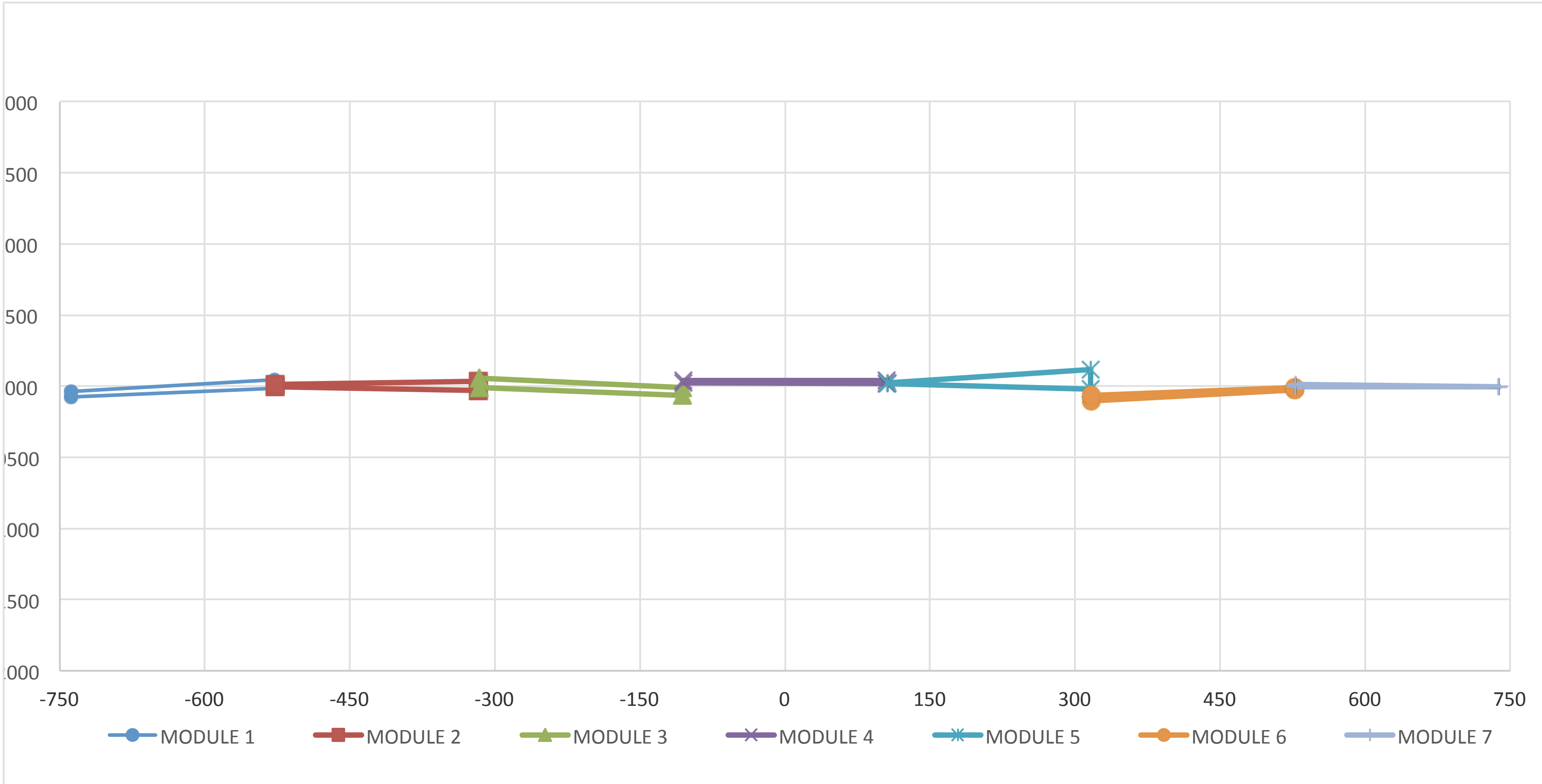


Max Deviation [mm] = 0.022
RMS [mm]=0.010

Stave Metrology – STAVE 0 - HS0_R

For each HIC the position of reference marker on the 4 corners was measured after each HS assembly
We report the deviations from the nominal position along x coordinate

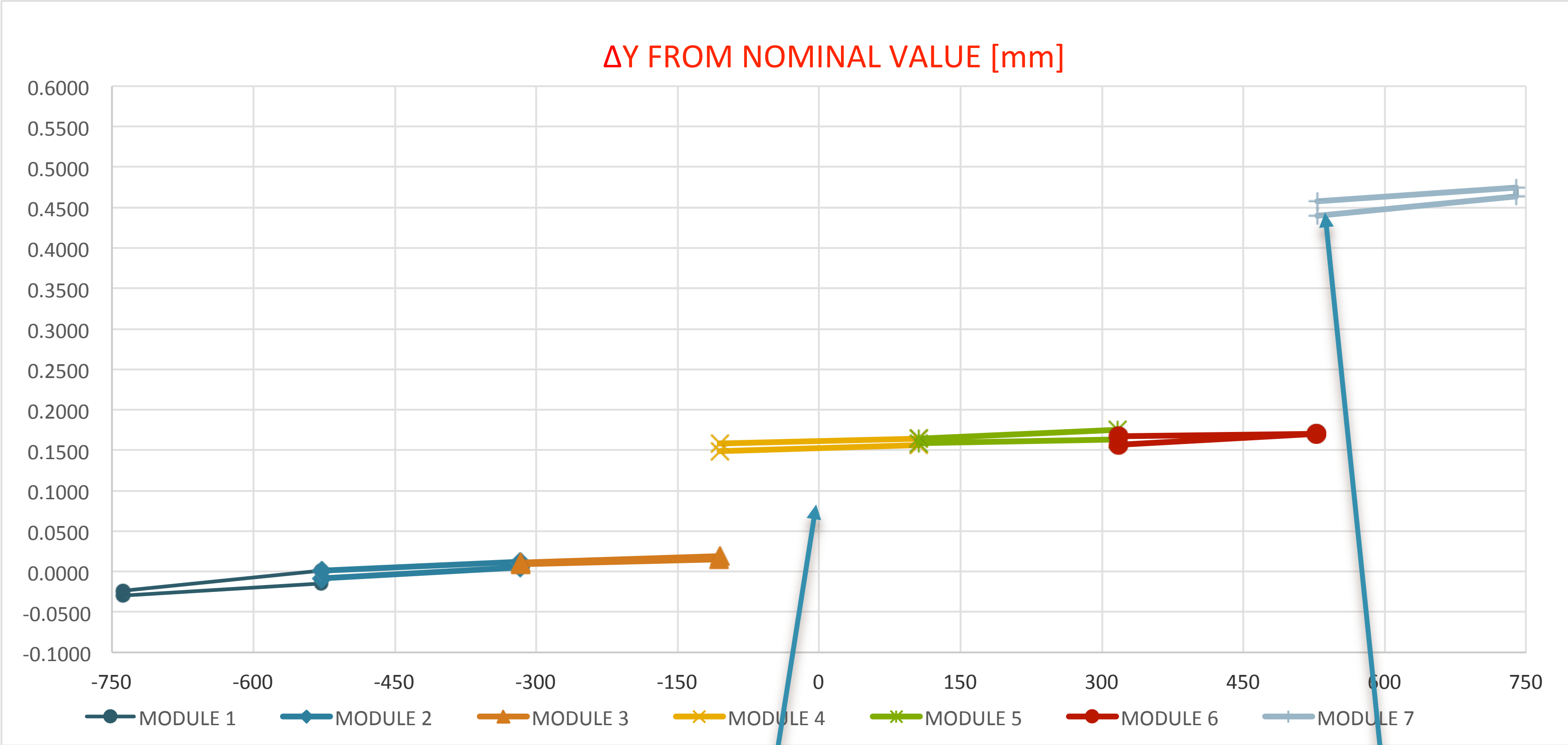
ΔX FROM NOMINAL VALUE [mm]



Max Deviation [mm] = 0.011
RMS [mm]=0.004

Stave Metrology – STAVE 0 - HS0_L

For each HIC the position of reference marker on the 4 corners was measured after each HS assembly
We report the deviations from the nominal position along Y coordinate.
Precise positioning along this coordinate depends on the precision of the TAB cut: for few HICs we cut with low precision due to alignment errors



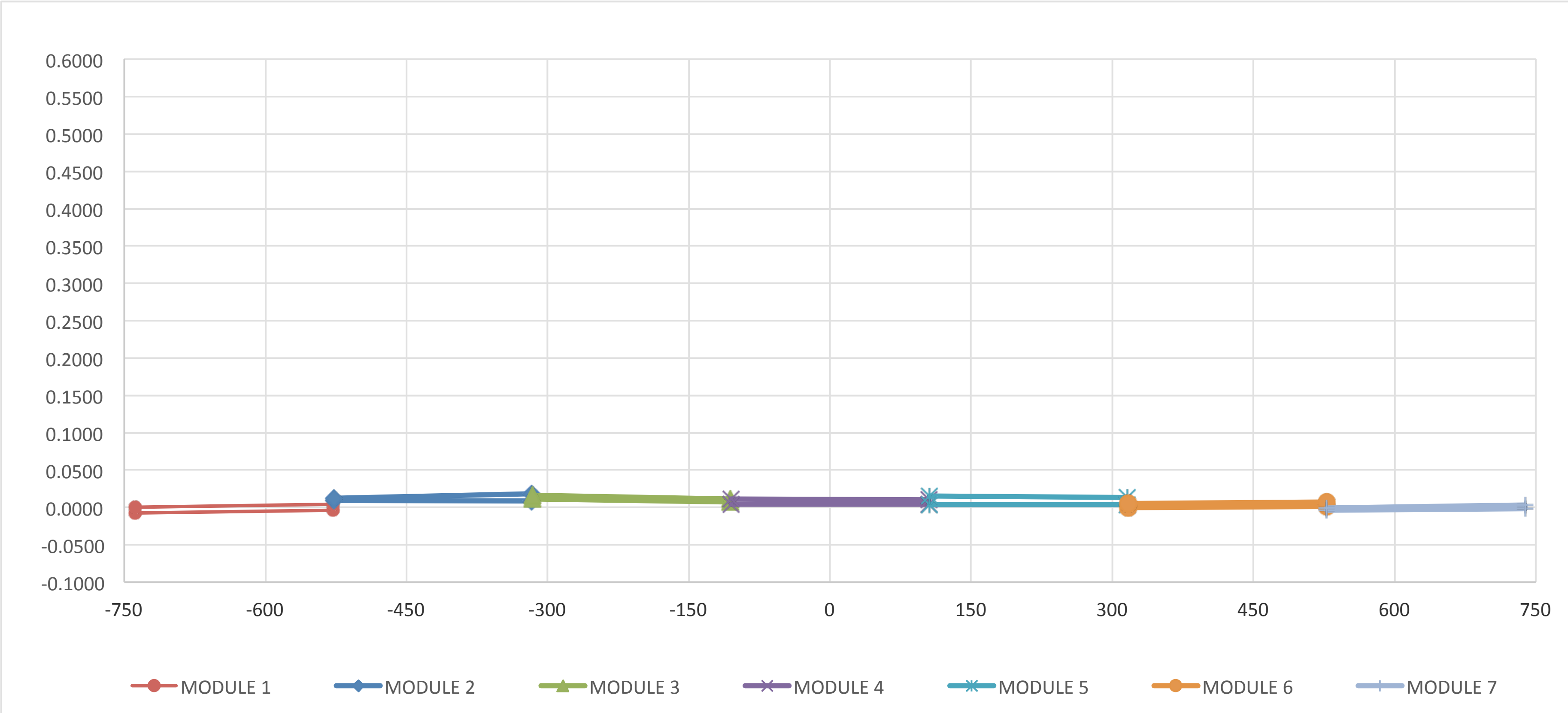
Problems in tab cut

Tab cut at ~200um

Tab cut at ~400um

Stave Metrology – STAVE 0 - HS0_R

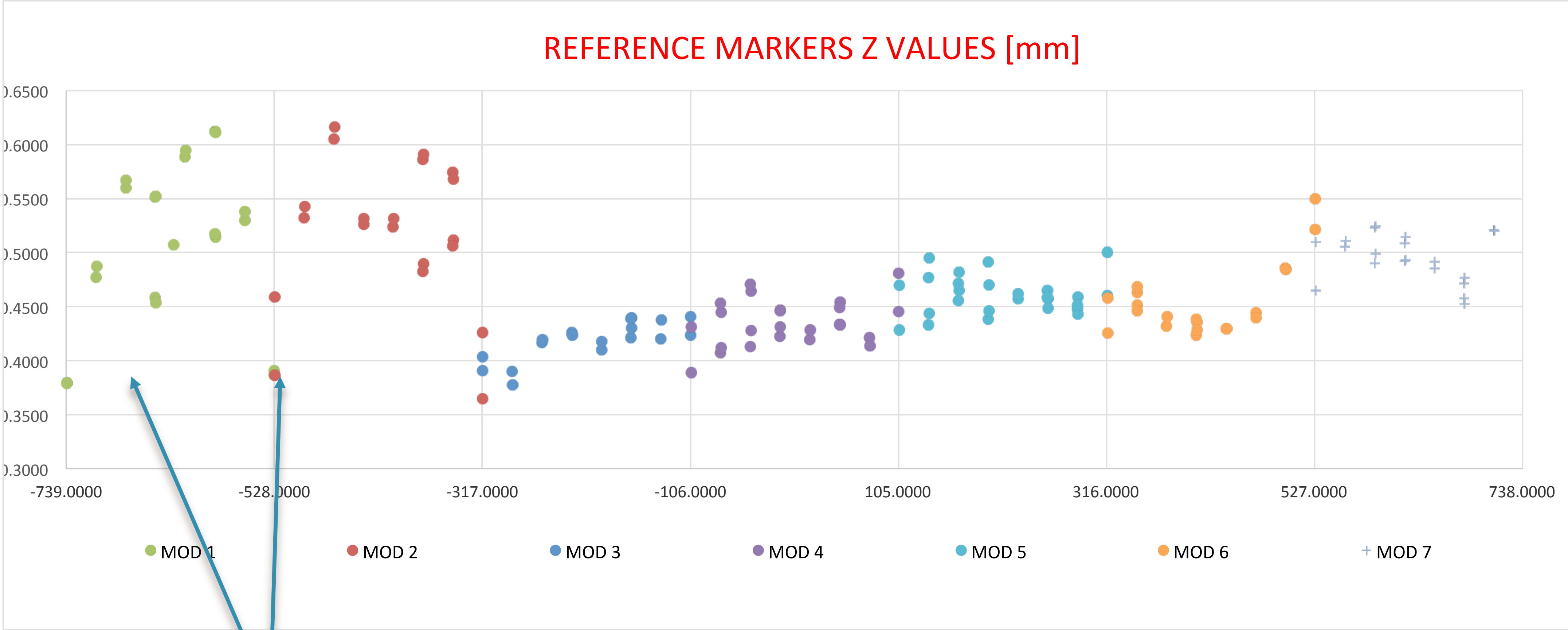
For each HIC the position of reference marker on the 4 corners was measured after each HS assembly
We report the deviations from the nominal position along Y coordinate.
Precise positioning along this coordinate depends on the precision of the TAB cut: TAB were all cut at 80-100μm from the sensor



Max Deviation [mm] = 0.0167
RMS [mm]=0.006

Stave Metrology – STAVE 0 - HS0_L

For each HIC the position of all visible reference markers were measured after each HS assembly
We report the deviations from the nominal position along Z coordinate.
Precise positioning along this coordinate depends on the planarity of the HIC, of the CP+glue, of the HIC gripper and of the HS Base

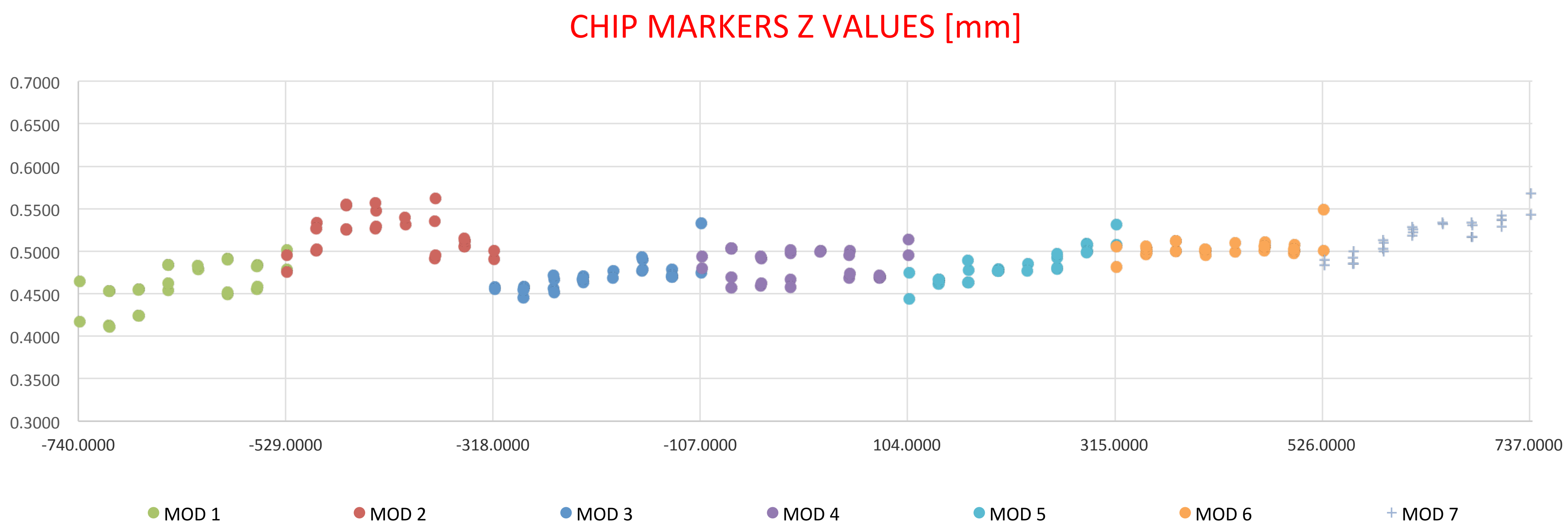


production gripper used

Issue with module gripper planarity: prototype gripper used

Stave Metrology – STAVE 0 - HS0_R

For each HIC the position of all visible reference markers were measured after each HS assembly
We report the deviations from the nominal position along Z coordinate.
Precise positioning along this coordinate depends on the planarity of the HIC, of the CP+glue, of the module gripper and of the HS Base

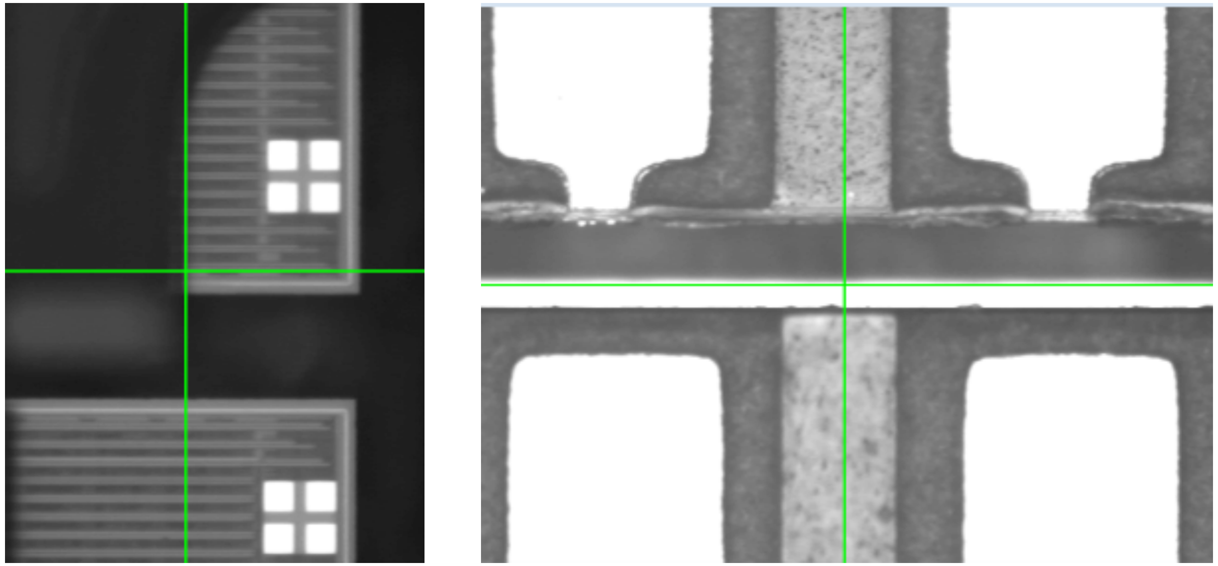


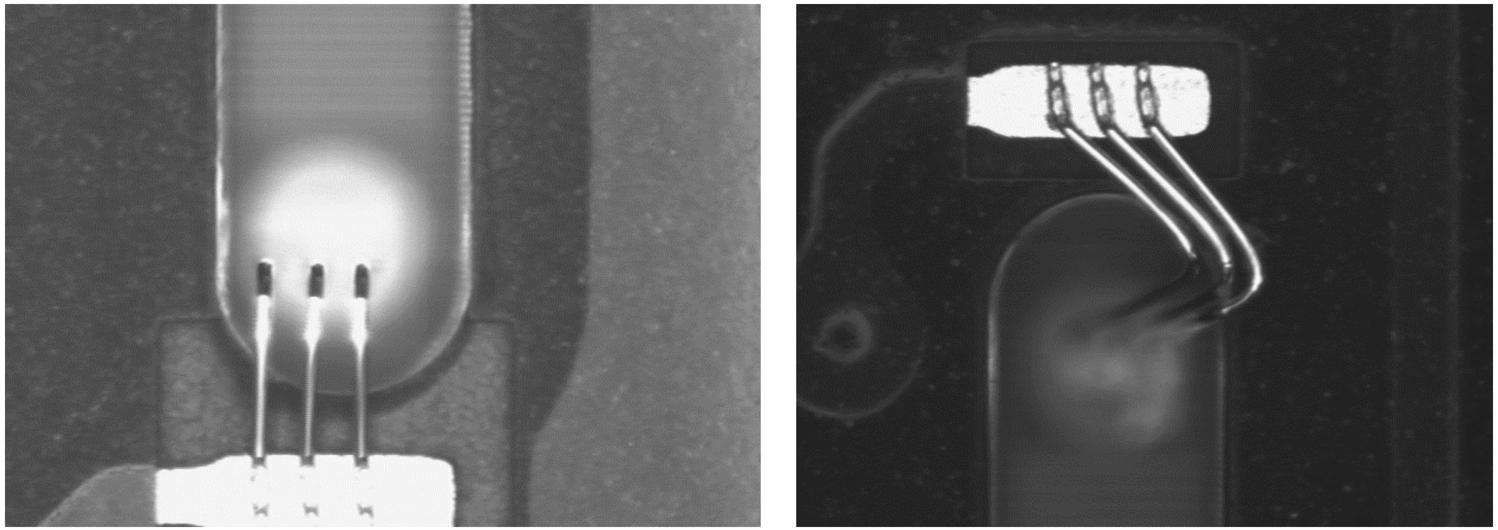
Max Deviation [mm] ~ 0.15
RMS [mm]=0.029
AVERAGE THICKNESS [mm]= 0.49

Stave Metrology – STAVE 0 - VISUAL INSPECTION

After each HS assembly a visual inspection using the CMM camera is performed
We aim to check relative alignment of HIC to HIC interconnection pads and possible damages of wire bonds during HIC manipulation

Visual inspection show good alignment of HIC to HIC interconnection pads





Visual inspection show NO wire bonding damage

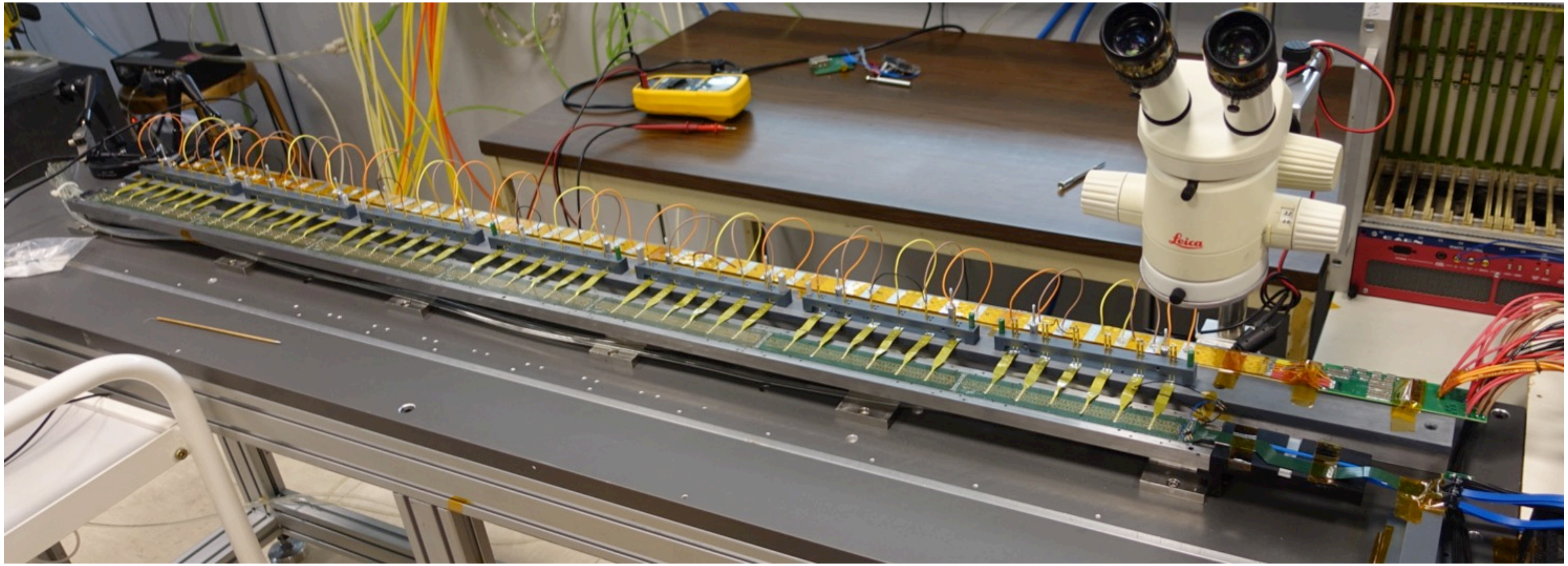
Stave Functional Characterization – Introduction

2 prototype HS have been assembled so far:

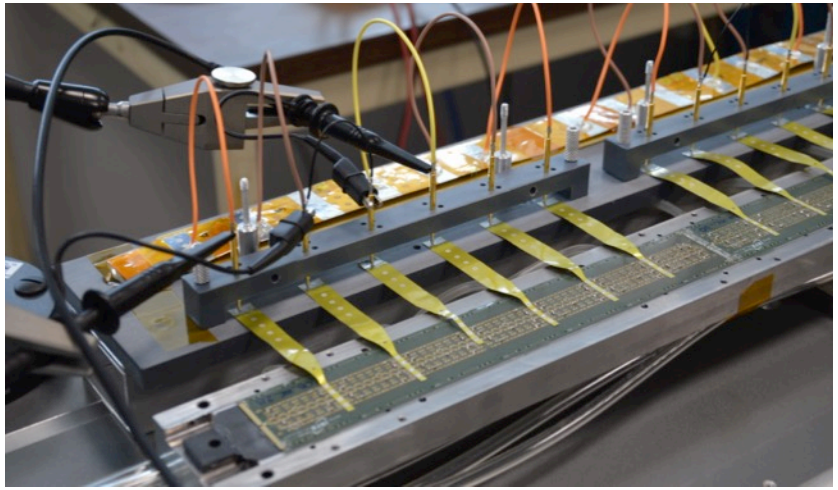
1. main purpose: test the assembly procedure till the functional tests (not all the HICs are of good quality)
2. functional HS, all HICs are of good quality

- compare performance of single HICs before and after the assembly on the HS
- check transmission along the CLK, CTRL and data lines
- operate concurrently the HICs

Stave Functional Characterization – HS test set up



- the HS is powered through a Power Bus connected to the Cross Cables of each HIC by means of wires + spring loaded probes
- each HIC can be powered/tested individually or all at the same time
- HIC are readout using both the MOSAIC and the prototype of the ITS RU. Data lines are connected to the readout through an extension soldered to HIC in position 1



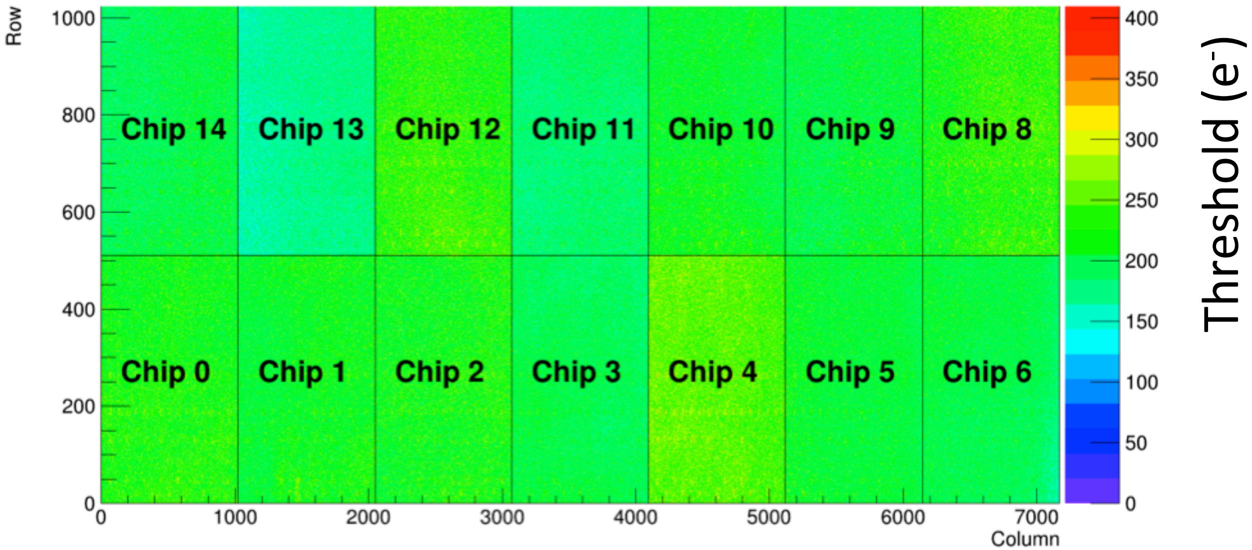
Functional Characterization – HIC map on the functional HS

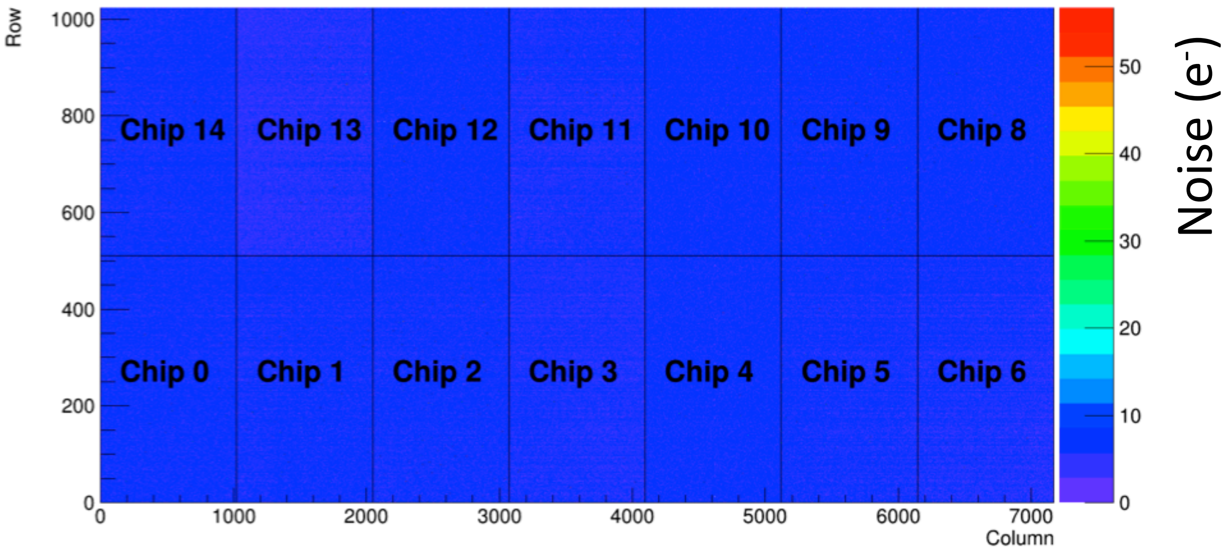
HIC POSITION	LINE A	LINE B	COMMENT	
1	X	X	NO CLK	NOT RESPONDING TO CTRL
2	✓	✓		
3	✓	✓		
4	✓	✓*		DRIVER STRENGHT ISSUE
5	✓	✓		
6	✓	✓		
7	✓	✓		

- HIC in position 1 has broken bonds on the data lines (CLK on line A, BUSY on line B), most likely during tab cutting or while soldering the extension to HIC 1

Threshold Scan of modules on Half-Stave

- Example of a **threshold map** for module in **position 5** (HIC 32)
- Test done with PLL STAGES = 1
- AVDD@1.75V and DVDD@1.77V (on module)





Thresholds and noise values are quite uniform for all the chips

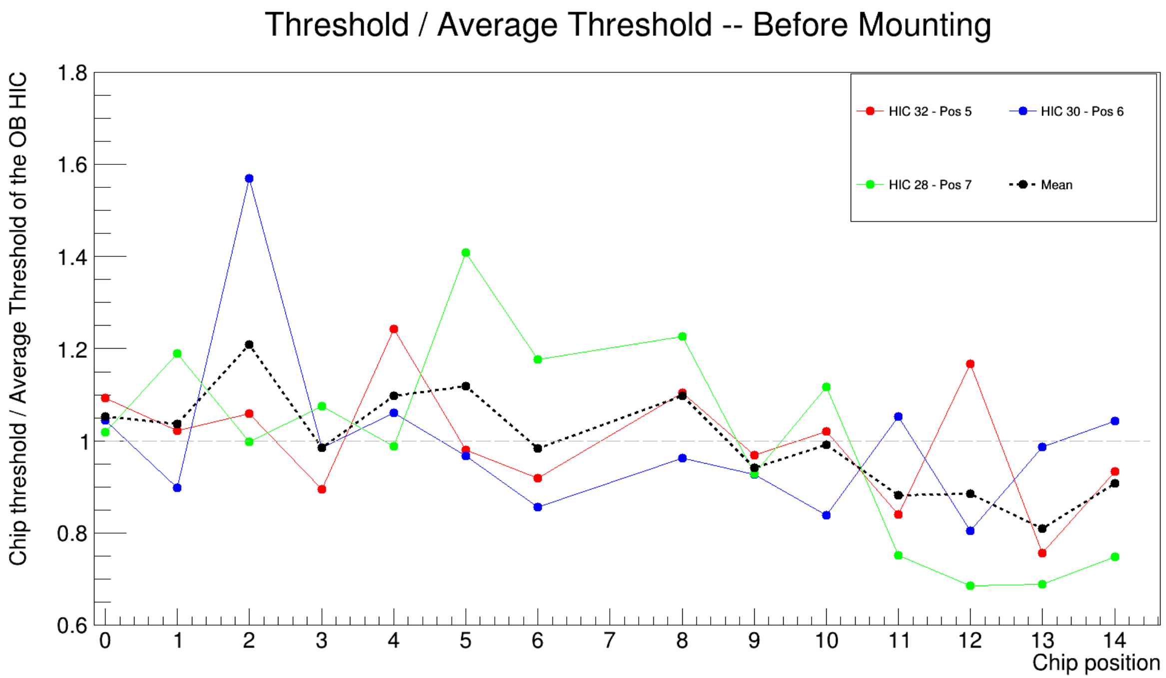
Threshold Scan of modules on Half-Stave – Threshold variation

Threshold vs. chip position for 3 different HICs (normalized to average of respective HIC)

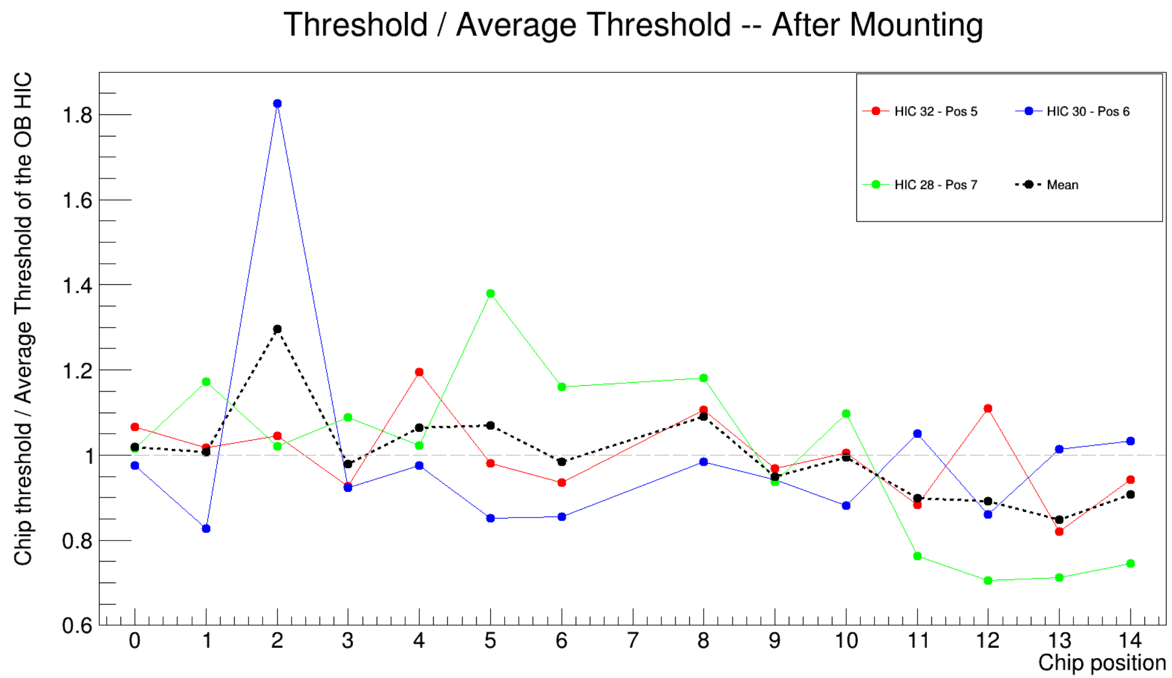
- No systematic trend visible, threshold variation dominated by random chip-to-chip variation

(In either case variation can be adjusted for)

- Values before/after mounting are **compatible**



Before mounting on HS

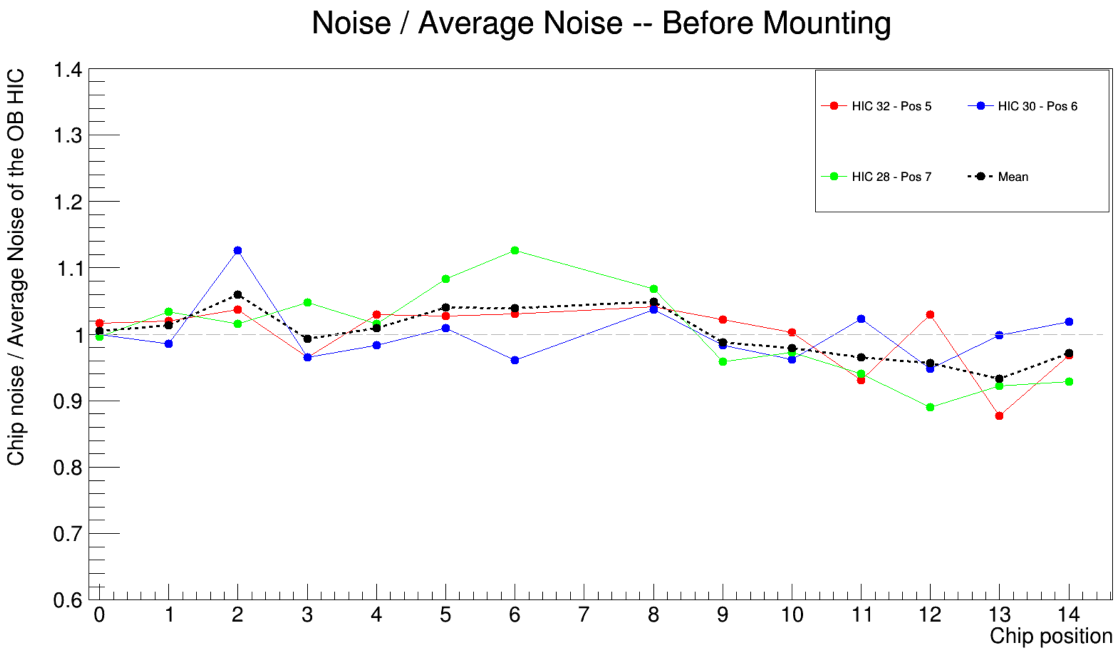


After mounting on HS

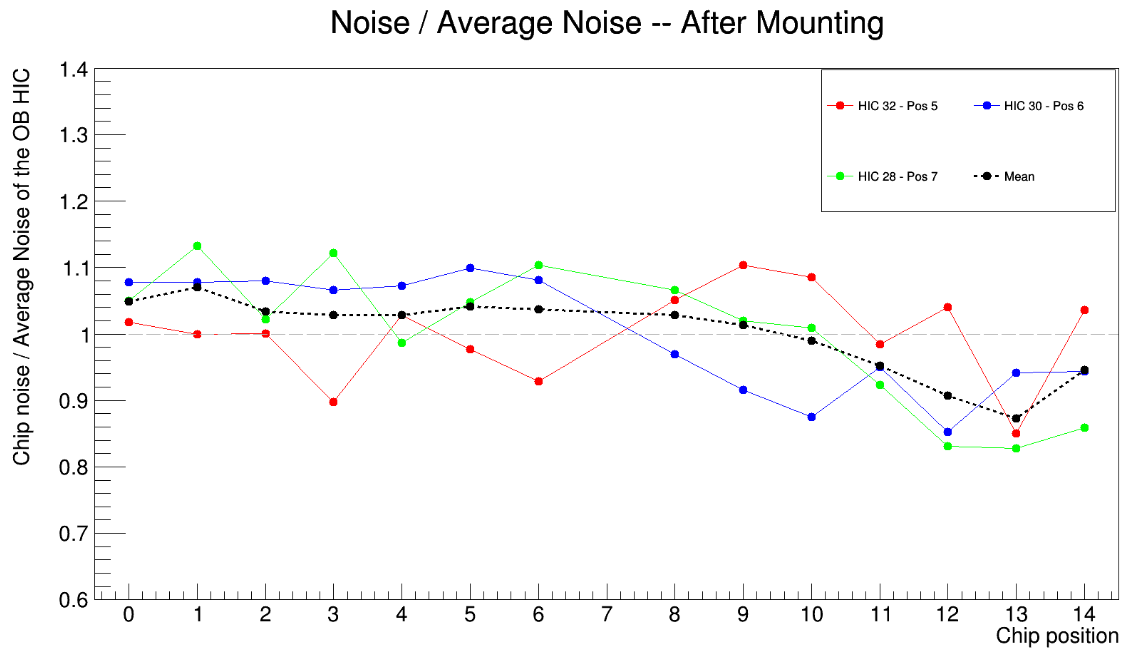
Threshold Scan of modules on Half-Stave – Noise variation

Noise vs. chip position for 3 different HICs (normalized to average of respective HIC)

- No systematic trend visible, noise variation dominated by random chip-to-chip variation
- (In either case variation can be adjusted for)
- **Compatible** value before/after mounting



Before mounting on HS

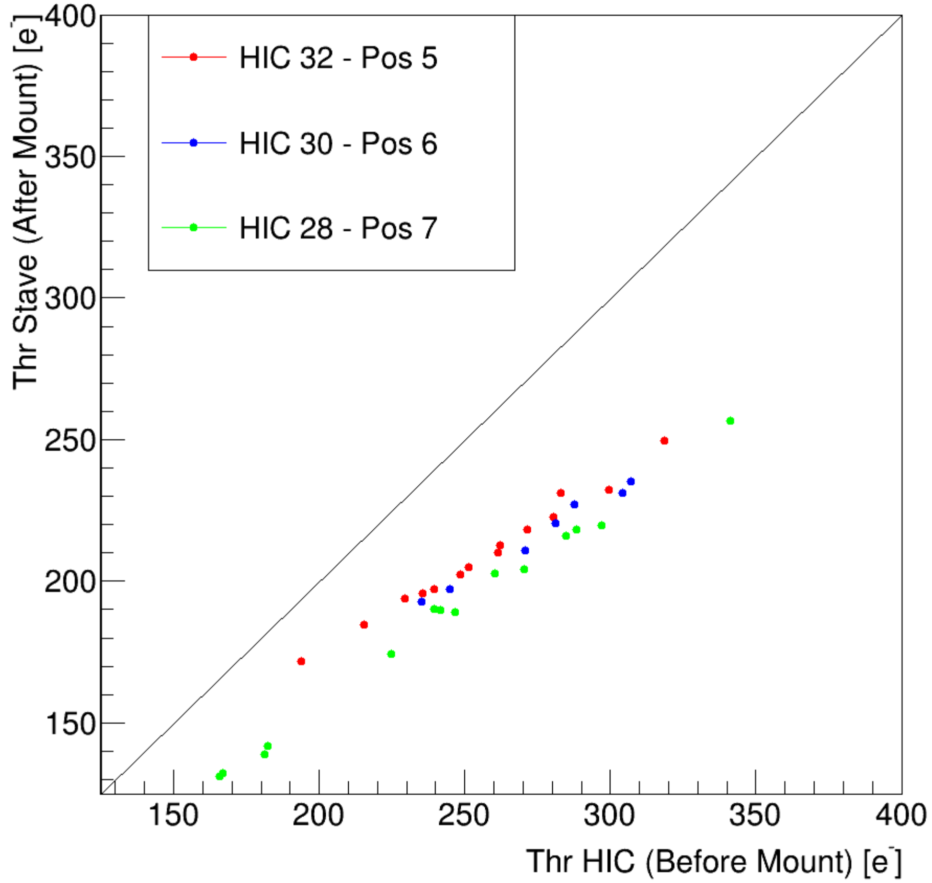


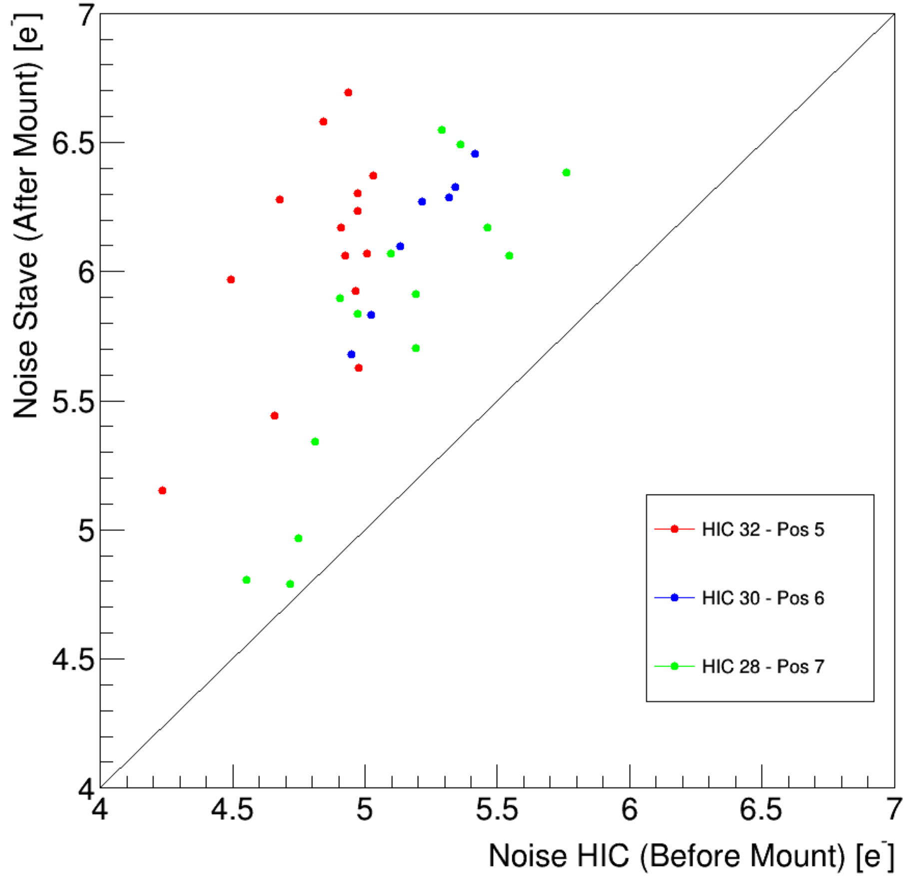
After mounting on HS

Correlation Threshold & Noise for HIC on HS vs HIC before mounting

Comparison of thresholds (left) and noises (right) (chip average) between HIC on Half-Stave and HIC before gluing on Cold Plate

- Absolute value depends on measurement condition, but threshold values clearly correlated

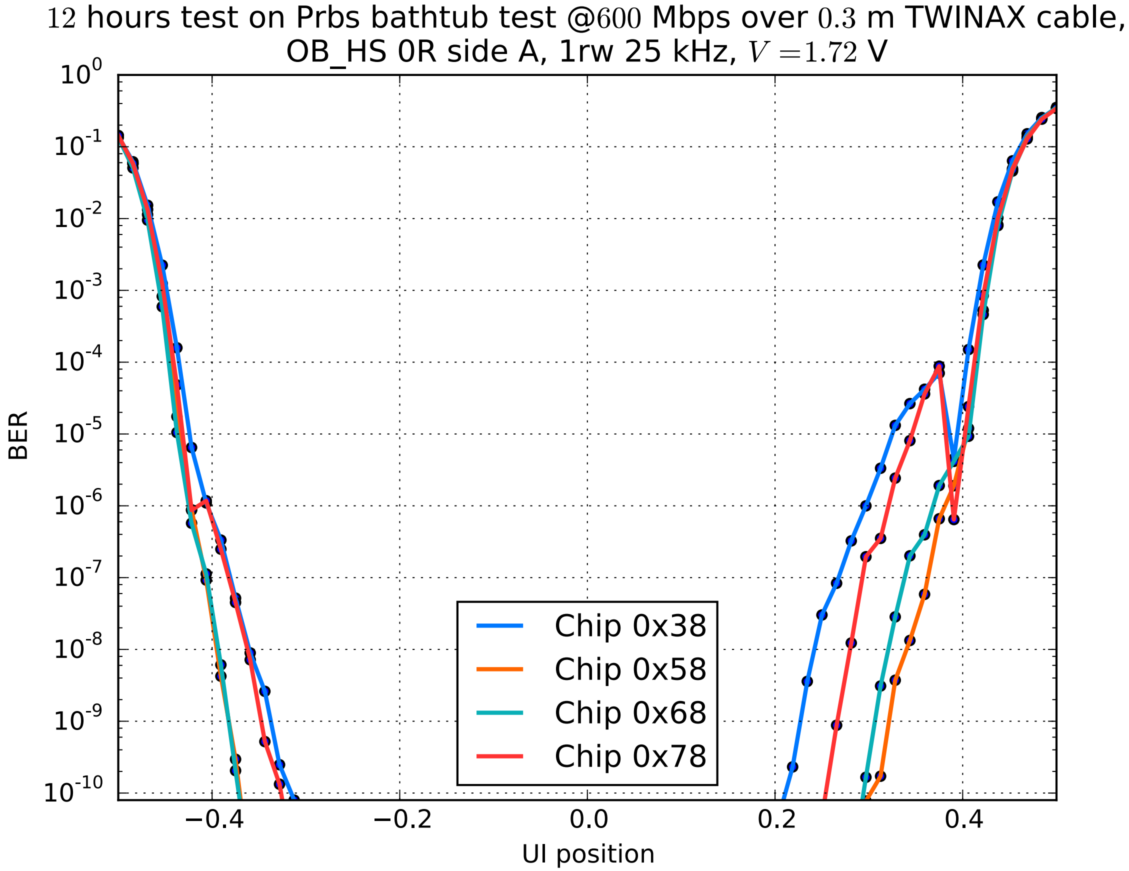




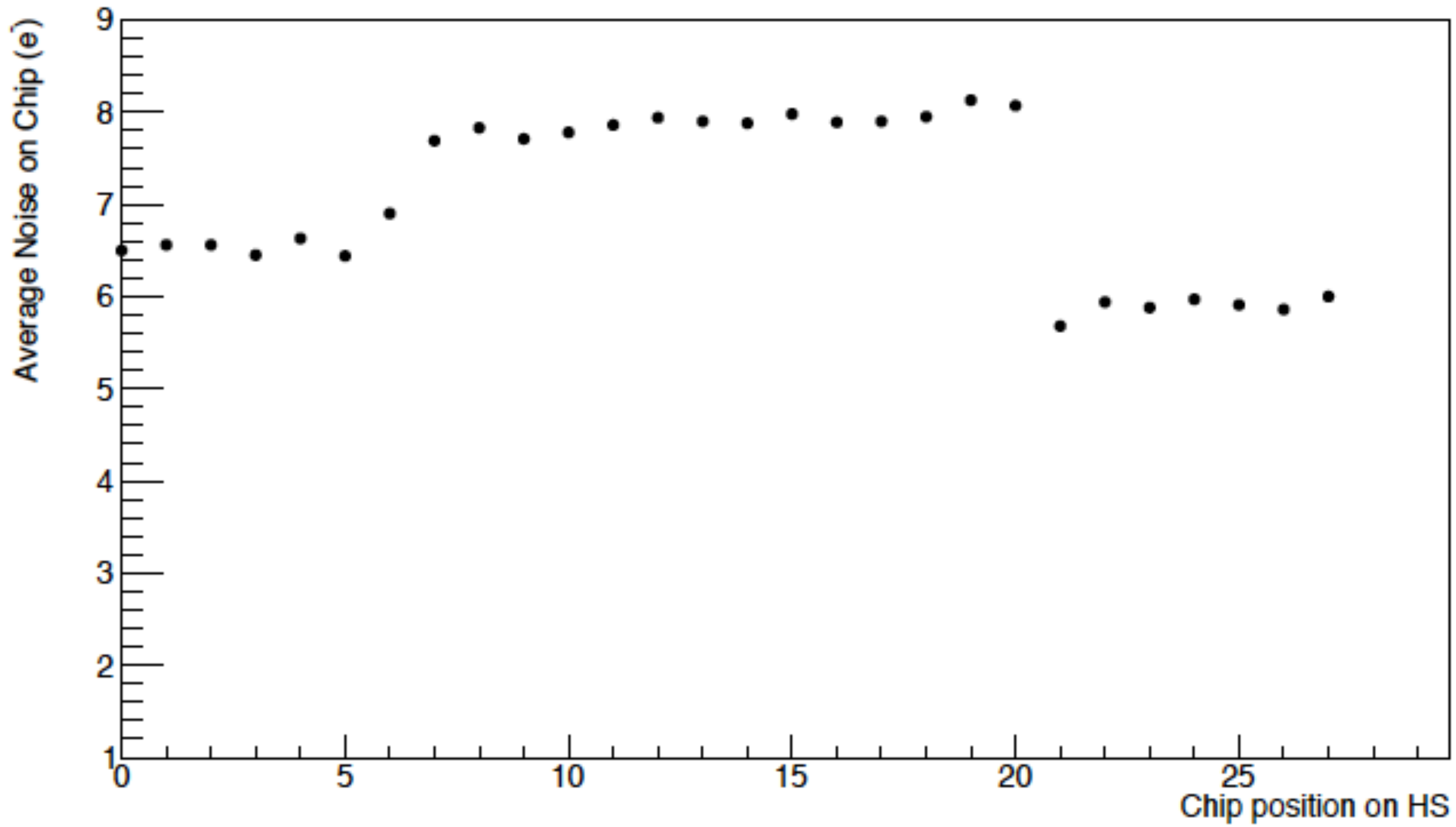
Functional Test Results - PRBS and Bathtub test

- The serial link was tested by transmitting a Pseudo Random bit Sequence (PRBS) on the serial link. The master chips were transmitting simultaneously a PRBS at 600 Mbps over the FPCs and 30 cm FireFly cable. All the chips (including the slaves) were configured for receiving triggers and were pulsed at 25 kHz. The chip registers are checked to confirm that each chip is receiving all the triggers that are sent. Each chip had 1 row unmasked
- The test was run for 12 hours without registering errors on the data link
- The total number of transmitted bits from each chip is 2.592 10^{13}. BER is 1.78 10^{-13} (CL = 0.99) for each master chip read out.

The results shown in the bathtub plot, taken while the PR
comparable to the one obtained on a HS prototype
with similar voltage

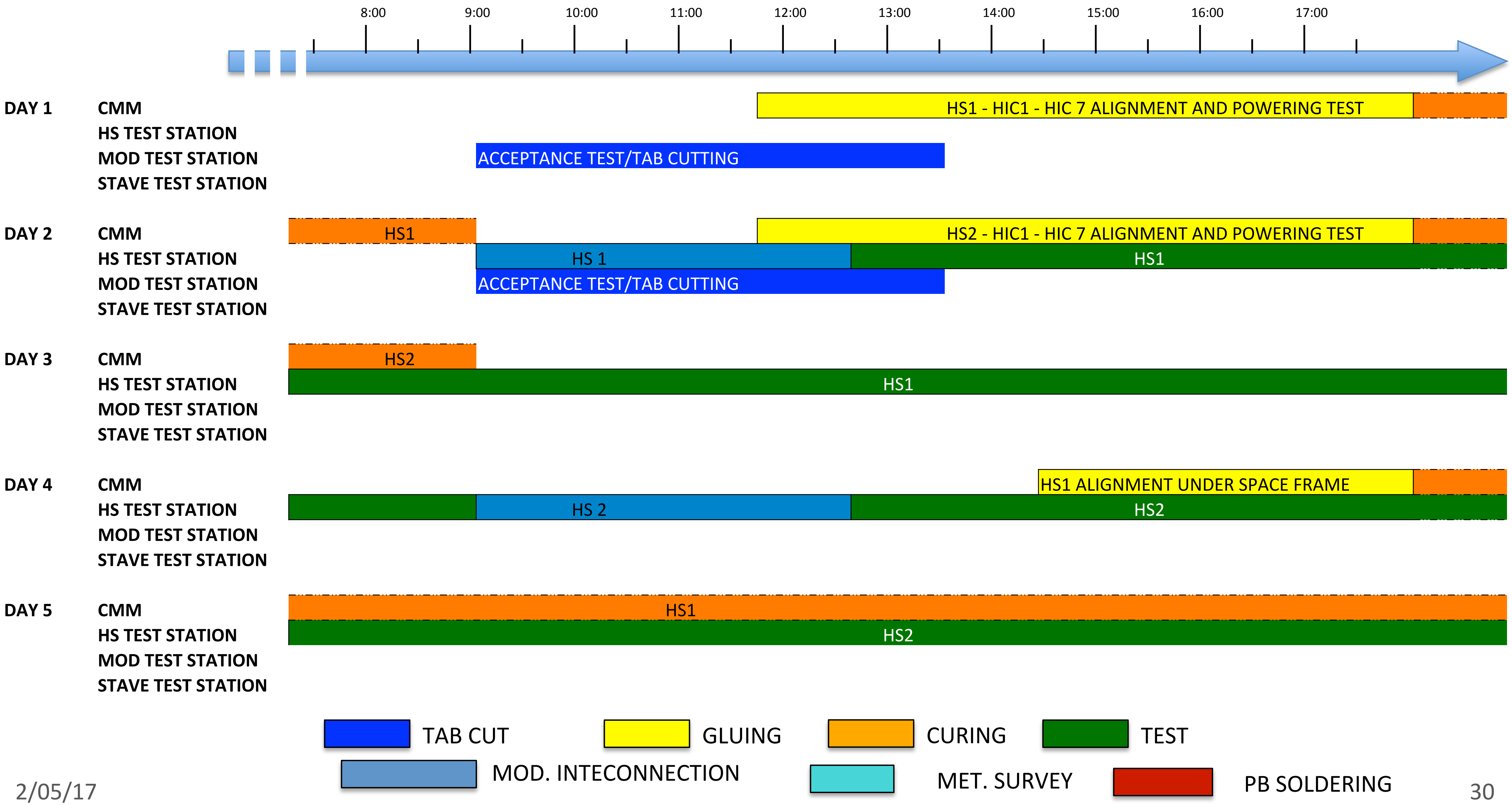


Functional Test Results – Noise scan on full HS

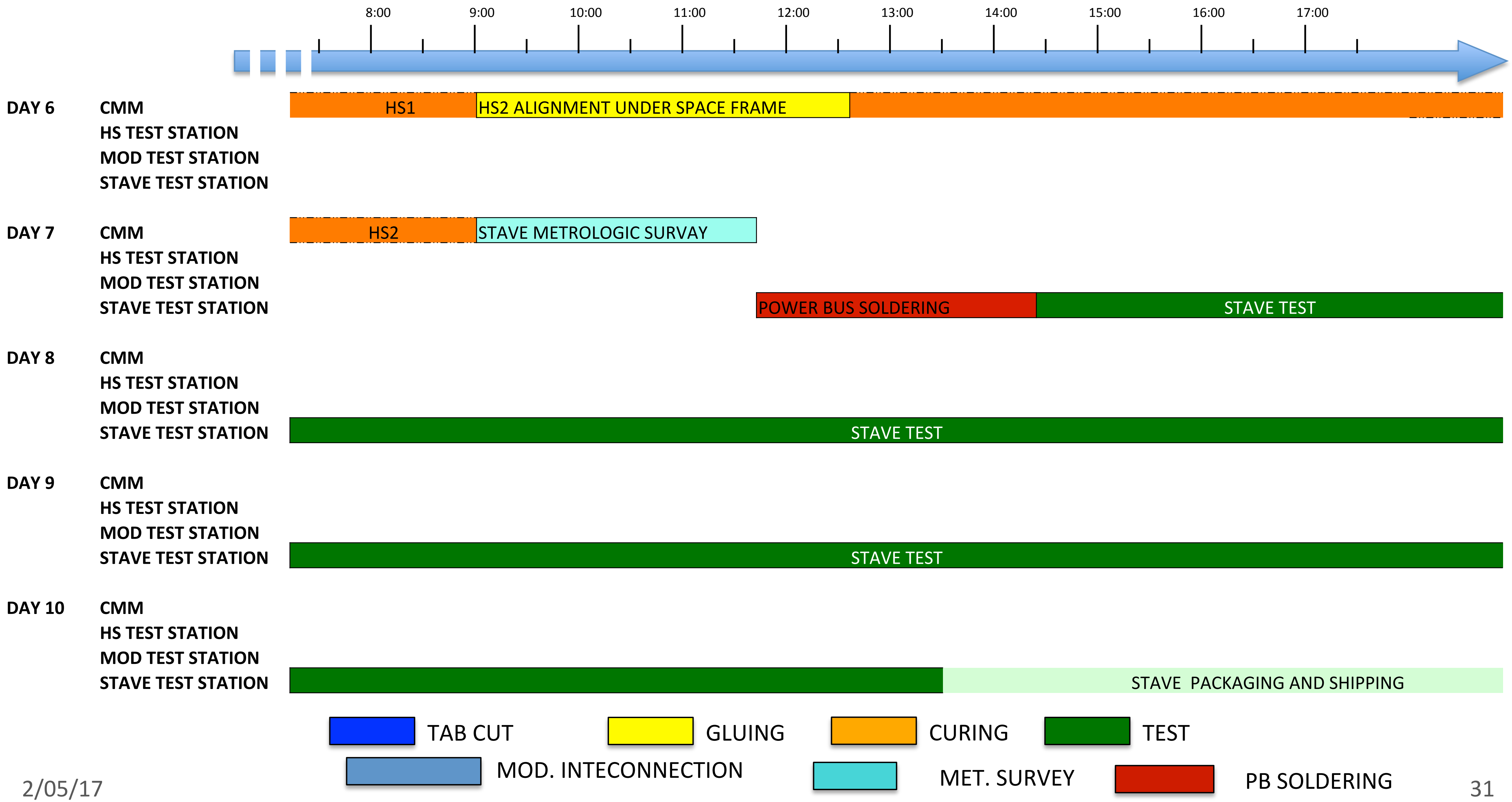


- Scans of thresholds and noise are ongoing on the full HS. All chips are operated concurrently.
- First results don't show any issues on data acquisition
- A slight increase of the noise value is visible (power supply and reverse bias are not optimized for noise)
- A value of noise <10e$^-$ is about 10 times smaller than the anticipated threshold setting of 100e$^-$ and will not significantly contribute to the fake-hit rate

Assembly procedure – Timing



Assembly procedure – Timing



OB stave assembly – Construction site preparation

The OB stave assembly will take place in 5 sites:
Torino (IT): responsible for Stave assembly procedure and tooling development
Daresbury (UK): OL
LNF (IT): OL
NIKHEF (NL): OL

LBNL (USA): ML

Tooling for OL was designed by INFN Torino and produced by SEL srl (IT)
Tooling for ML was designed and produced at LPSC Grenoble (FR)

The full set of tools was sent to the OL sites and the laboratories are being prepared for the training phases and for the start of production

Tools for ML sites will be sent to LBNL within middle May. Planarity issues of HS bases were found, these tools are being machined by SEL srl to assure the necessary planarity

OB stave assembly – Laboratory readiness and team training

Verification of the laboratory readiness and extensive training of the teams involved in the construction is foreseen

Laboratory readiness: each site will organize a workshop which includes an "hands on session" as soon as the CMM and tools are installed and ready for production.

First workshop will be in LNF May 24-25th, Daresbury, Nikhef and LBNL will follow. Schedule will be defined in the next weeks

Team training: 2 kind of training are foreseen

- assembly tools and procedures: divided in 3 phases
- test procedures: based on single chip and HIC test set-up

OB stave assembly – Torino (IT)

The Torino site was equipped with prototype tools and contributed to the development of tools and procedures and to the production of Dummy Staves for mechanical tests and the Stave 0

Status of the laboratory: READY FOR PRODUCTION
Training on assembly procedures: DONE
Training on test procedures: DONE

- **Clean Room space optimized**
- **Plants:**
  - **Vacuum**
  - **Compressed air**
- **Mitutoyo Crysta Apex S 9206: operational**
- **All jigs installed and used for production of mechanical prototypes and stave 0**

OB stave assembly – LNF (IT)

The LNF site was equipped with prototype tools and contributed to the validation of tools and procedures and to the production of Dummy Staves for mechanical tests

Status of the laboratory: READY FOR PRODUCTION
Training on assembly procedures: DONE
Training on test procedures: ONGOING

- **Clean Room space optimized**
- **Plants:**
  - **Vacuum**
  - **Compressed air**
- **Mitutoyo Crysta Apex S 9206: operational on Atlas GA5FF**
- **Final jig installed and ready**
- **Custom HS soldering table under construction**
- **Grey area (used ALPIDE single chip tests) is being prepared for Stave operations (PB soldering and tests)**

OB stave assembly – Daresbury (UK)

Status of the laboratory: ALMOST READY
Training on assembly procedures: TO BE DONE
Training on test procedures: TO BE DONE

- **New Clean Room available**
- **Plants:**
  - **Vacuum**
  - **Compressed air**
- **Mitutoyo Crysta Apex S 9206: delivered and being commissioned**
- **Tools will be installed in the next 2 weeks**

OB stave assembly – NIKHEF (NL)

Status of the laboratory: READY FOR PRODUCTION
Training on assembly procedures: ONGOING
Training on test procedures: to be done

- Clean room ready
- Mitutoyo Crysta Apex S 9206 operational
- Plants:
  - Vacuum
  - N2
  - Compressed air
- Glue dispenser
- Tables for additional stations: To be done
  - Soldering station
  - Gluing station
  - Test station
- Stave assembly tools received
- Ready for training session

OB stave assembly – LBNL (USA)

Status of the laboratory: ALMOST READY
Training on assembly procedures: TO BE DONE
Training on test procedures: TO BE DONE

- **Clean room being prepared**
- **Mitutoyo Crysta Apex operational**
- **Stave assembly tools being revised at SEL**

- **ready for training on site early summer**

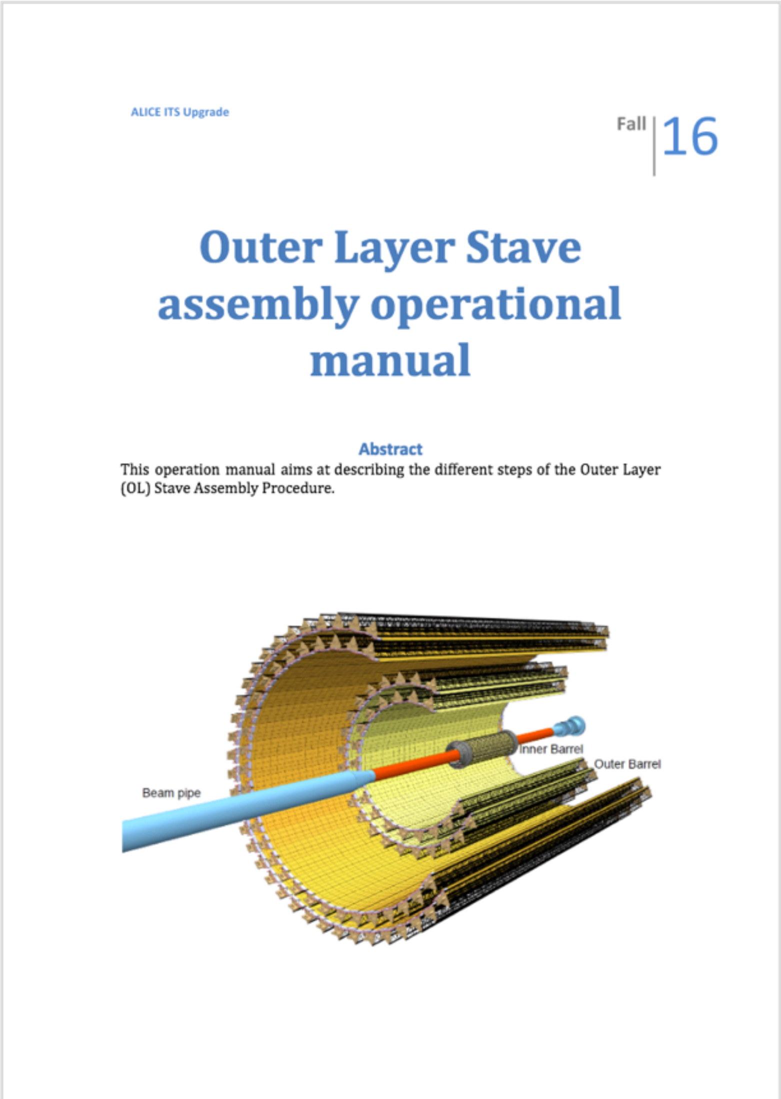
OB stave assembly – Assembly training program

ALICE

Teams training is divided into 3 phases

- Phase 1: WHERE: Torino, DURATION: 5 days, CREW: Torino+ construction site
  - tooling description
  - gluing procedure
  - CMM programs description and test
- Phase 2: WHERE: each site, DURATION: 3-4 days, CREW: Torino+ construction site
  - CMM program migration annd validation
  - module alignment test
  - HS to SF alignment test (with bare CP)
- Phase 3: WHERE: each site, DURATION: 4 weeks, CREW: construction site
  - gluing test
  - FPC-FPC interconnection tests using test structures
  - dummy module alignment and gluing to dummy CP
  - realistic dummy modules alignment and gluing to real CP + metrology
  - FPC-FPC interconnection
  - HS alignment and gluing to SF
  - stave final metrology

OB stave assembly – Assembly operation manual



ALICE ITS Upgrade

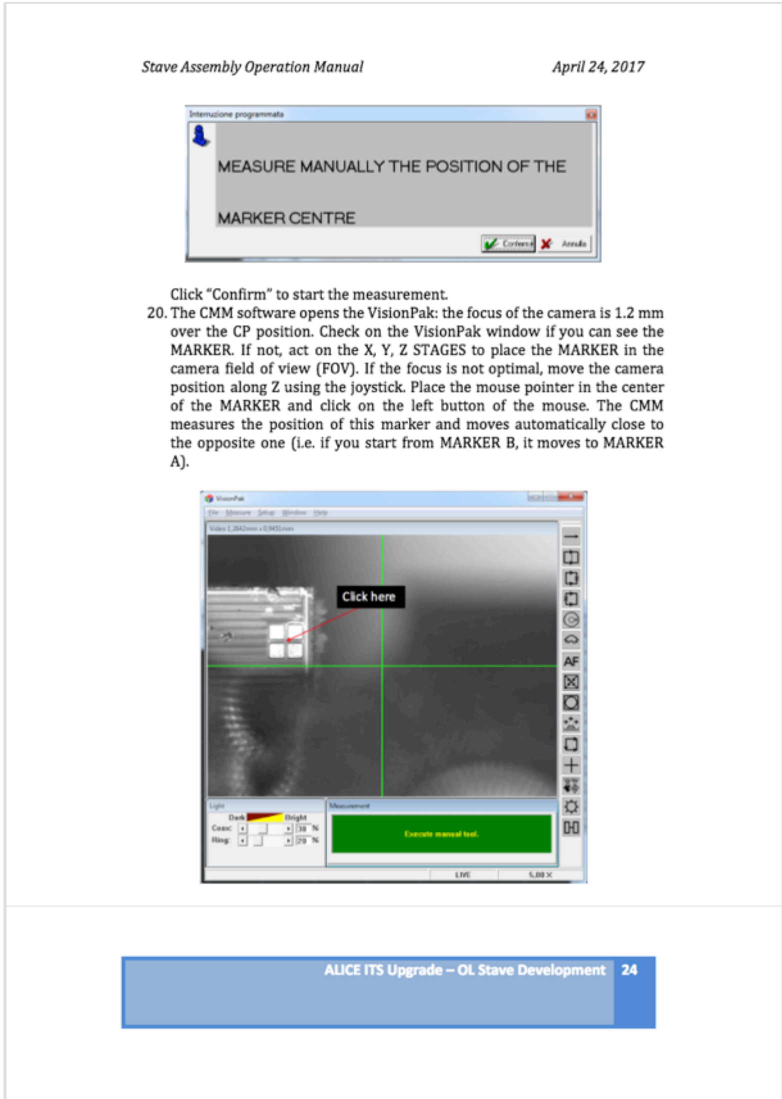
Fall | 16

Outer Layer Stave assembly operational manual

Abstract

This operation manual aims at describing the different steps of the Outer Layer (OL) Stave Assembly Procedure.

Beam pipe
Inner Barrel
Outer Barrel



Stave Assembly Operation Manual *April 24, 2017*

MEASURE MANUALLY THE POSITION OF THE MARKER CENTRE

Click "Confirm" to start the measurement.

20. The CMM software opens the VisionPak: the focus of the camera is 1.2 mm over the CP position. Check on the VisionPak window if you can see the MARKER. If not, act on the X, Y, Z STAGES to place the MARKER in the camera field of view (FOV). If the focus is not optimal, move the camera position along Z using the joystick. Place the mouse pointer in the center of the MARKER and click on the left button of the mouse. The CMM measures the position of this marker and moves automatically close to the opposite one (i.e. if you start from MARKER B, it moves to MARKER A).

Click here

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OB stave assembly – Assembly training timetable

Draft schedule of training plan

LABORATORY	training	site	DATE
NIKHEF	phase 1	TURIN	Done
	phase 2	Amsterdam	May 27
	phase 3		June
LBNL	phase 1	TURIN+LNF	May 15-26
	phase 2	Berkeley	June 26
	phase 3		July
DARESBURY	phase 1	TURIN+LNF	June 5
	phase 2	Daresbury	June 12
	phase 3		June-July

Summary

- The OB Stave Assembly procedure was developed and tested. Tooling for the Stave assembly were produced and successfully used to assemble stave 0
- Geometrical survey of the constructed prototype confirms that assembly precision is within limits

1. **PLANARITY OF GRIPPERS MUST BE MEASURED CAREFULLY**
2. **WIRE BONDS ON THE HIC EDGES ARE THE MOST DELICATE (CLK AND BUSY): PROTECT WITH DROP OF GLUE?**
3. **TAB CUT CRITICAL FOR WIRE BONDS ON THE DATA LINES: ADD HOLES FOR WING PINS, OPTIMIZE HOLES ON THE HIC CORNER**
4. **EXTENSION MUST BE GLUED TO CP BEFORE SOLDERING, TO AVOID STRESS ALONG STAVE AXIS**

Summary

ALICE

- Testing tools and procedures are being used for HS characterization and will be optimised in the following weeks using this first test experience
- Tests on the functional HS are ongoing: results of the tests done so far don't show any issues due to the assembly of the HICs on the HS

1. **OUTPUT OF HIC TESTS MUST BE VERY DETAILED. RAW DATA FILES OF SCAN RESULTS SHOULD BE MADE AVAILABLE TO COMPARE WITH RESULTS OF SIMILAR TESTS BEFORE/AFTER TAB CUTTING (SEE MARKUS' PRESENTATION)**
2. **HICS MUST BE CLASSIFIED ACCORDING TO DRIVER STRENGHT AND HIC POSITION ON THE HS CHOSEN ACCORDINGLY**
3. **POWERING SET UP NEEDS TO BE OPTIMIZED:**
   - SPRING PROBES ARE USEFUL FOR TESTING PURPOSES
   - THIN U-SHAPED WIRES COULD BE THE REASON FOR THE INCREASE OF NOISE VALUES
4. **MOSAIC FIRMWARE NEEDS TO BE UPDATED (SEE MARKUS' PRESENTATION)**

Next steps

1. complete test of HS0_R:
    - MOSAIC to read out single modules in different powering schemes (single power adaptor or Power Bus)
    - RU to read out the full HS
    - optimize powering set-up

2. proceed to stave assembly:
    - glue HS0_R and HS0_L to the SF ?
    - retest HS0_L with RU, glue HS0_L to the SF, solder PB and test the partial stave

    - assemble a new HS0_L with working HICs
    - assemble 2 new HS