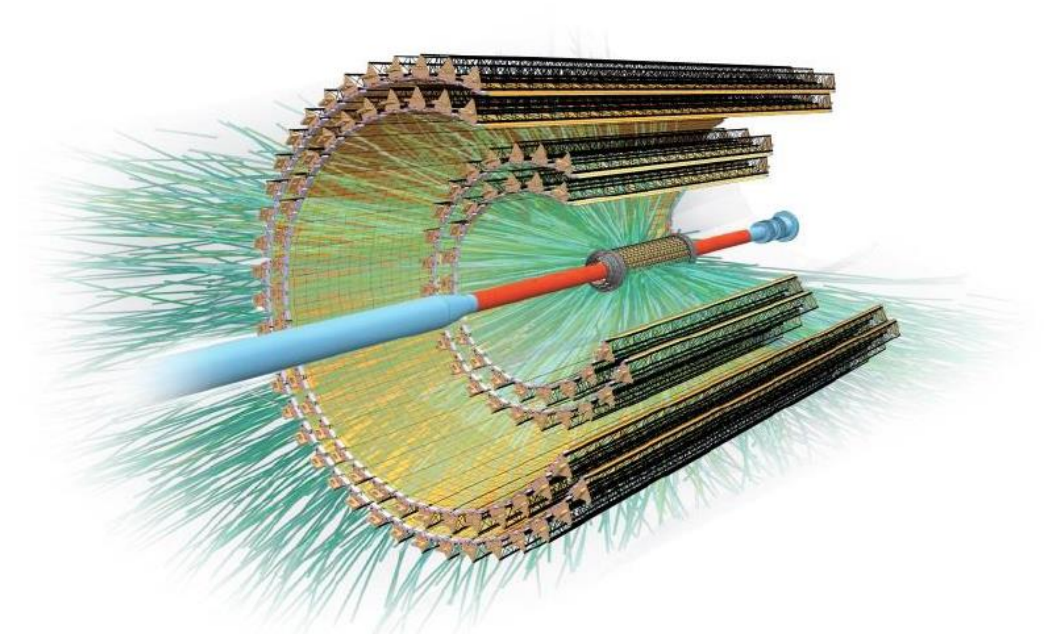
THE OUTER BARREL STAVE CONSTRUCTION OF THE ALICE ITS UPGRADE

S.COLI- INFN TO



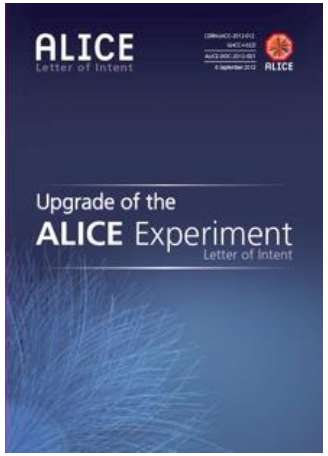
OUTLINE

- ALICE UPGRADE INTRODUCTION
- ITS UPGRADE GEOMETRY CONSTRAINTS AND ASSEMBLY STRATEGY
- THE OUTER BARREL STAVE ASSEMBLY PROCEDURE AND TOOLS
- FIRST RESULTS
- CONCLUSION

GOALS OF THE ALICE UPGRADE-MAIN REQUIREMENTS FOR THE NEW ITS

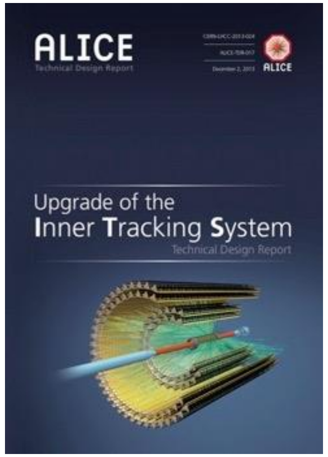
Physics Goal ➔ high-precision measurements of QGP properties

- Open Heavy Flavours (charm & beauty, mesons & baryons) and Quarkonia down to zero p_T to investigate
  - thermalisation, hadronization, recombination, temperature evolution of the QGP
- Vector mesons and low-mass di-leptons to investigate
  - Chiral-symmetry restoration, virtual thermal photons emission
- High-precision measurement of light (anti-)nuclei and hyper-nuclei to study
  - Nucleo-synthesis, exotics



Main requirements for the new Inner Tracking System:

- High tracking efficiency and resolution at low p_T (60% @ 100 MeV/c)
  - Increase granularity, reduce material budget
- Excellent secondary vertex resolution (Λ_c $c\tau$~60 μm)
  - Move closer to Interaction Point (IP), new beam pipe, smaller diameter
- High-statistics, un-triggered data sample (>10 nb^{-1} Pb-Pb)
  - Increase readout rate, reduce data size (online data reduction)



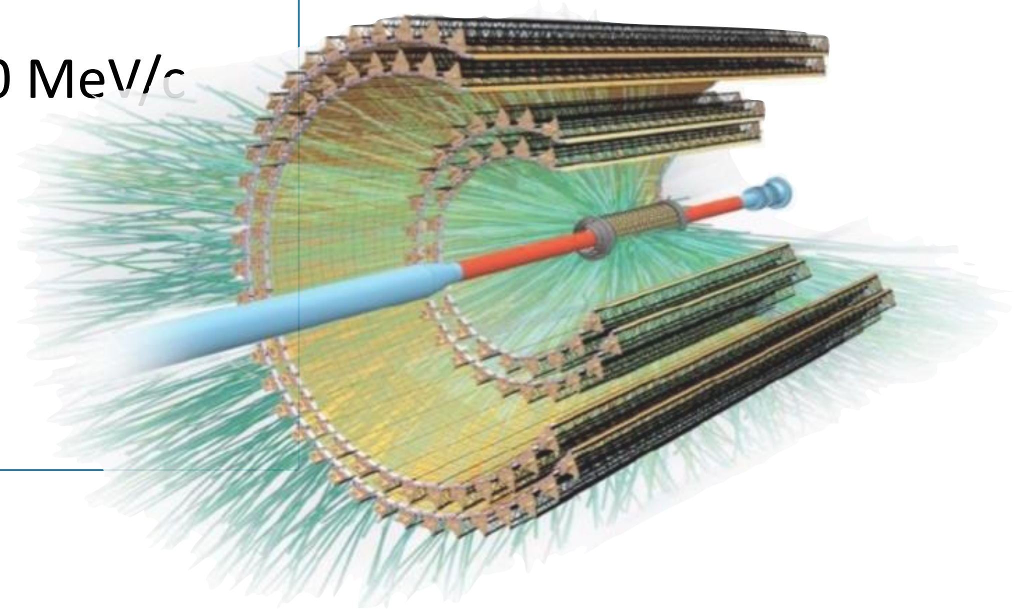
ITS UPGRADE OBJECTIVES

ALICE

Improve impact parameter resolution:

by a factor ~3 in transverse plane (rϕ) and ~5 in z at p_T=500 MeV/c

- get closer to IP: 39mm ➔ **23mm (innermost layer)**
- reduce material budget: ~1.14% X_0 ➔ **~0.3% X_0** (inner layers)
- reduce pixel size: 50x425μm^2 ➔ **about 30x30 μm^2**
- Spatial resolution: currently 12 μm x 100 μm (SPD) ➔5 μm x 5 μm



Improve tracking efficiency and p_T resolution at low p_T

- 6 layers ➔ **7 pixel layers**

Exploit LHC luminosity increase ➔Fast readout

- **readout of Pb-Pb collisions up to 100 kHz** and 200kHz for pp collisions

Withstand radiation load (10 years operation):

- TID (Total Ionizing Dose): ~ 270 krad,
- NIEL (Non Ionizing Energy Loss): ~1.7×10^{12} 1MeV n_{eq}/ cm^2

Fast insertion and removal

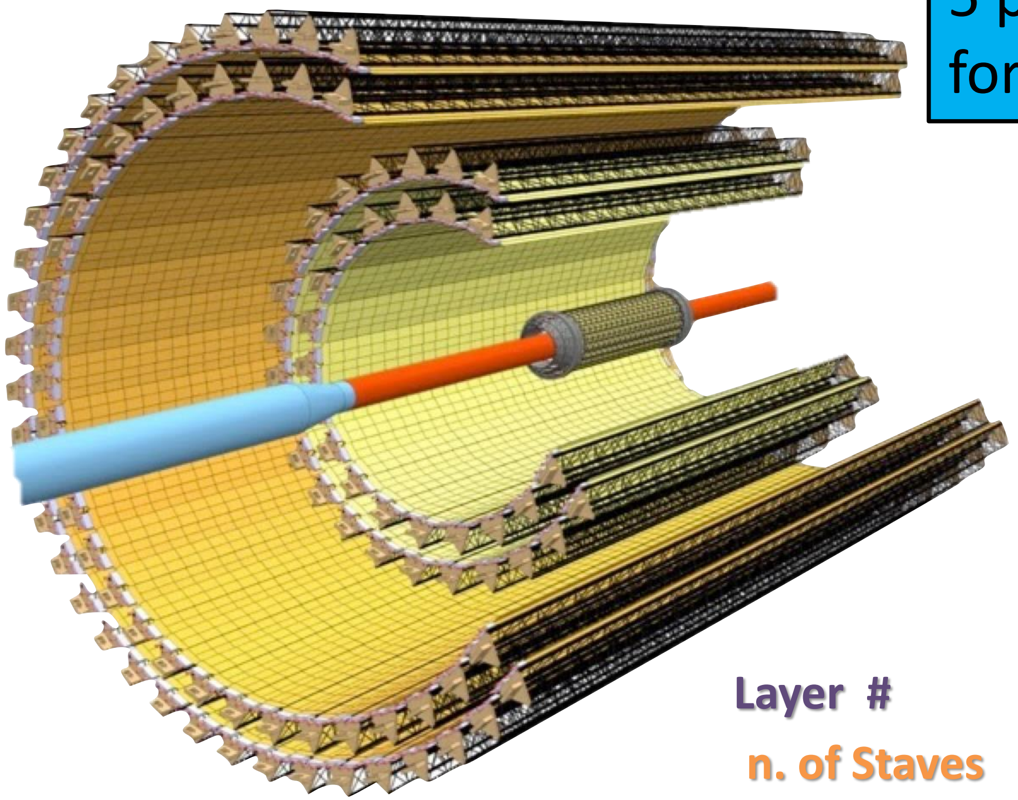
- possibility to **replace non-functioning detector staves during yearly shutdown**

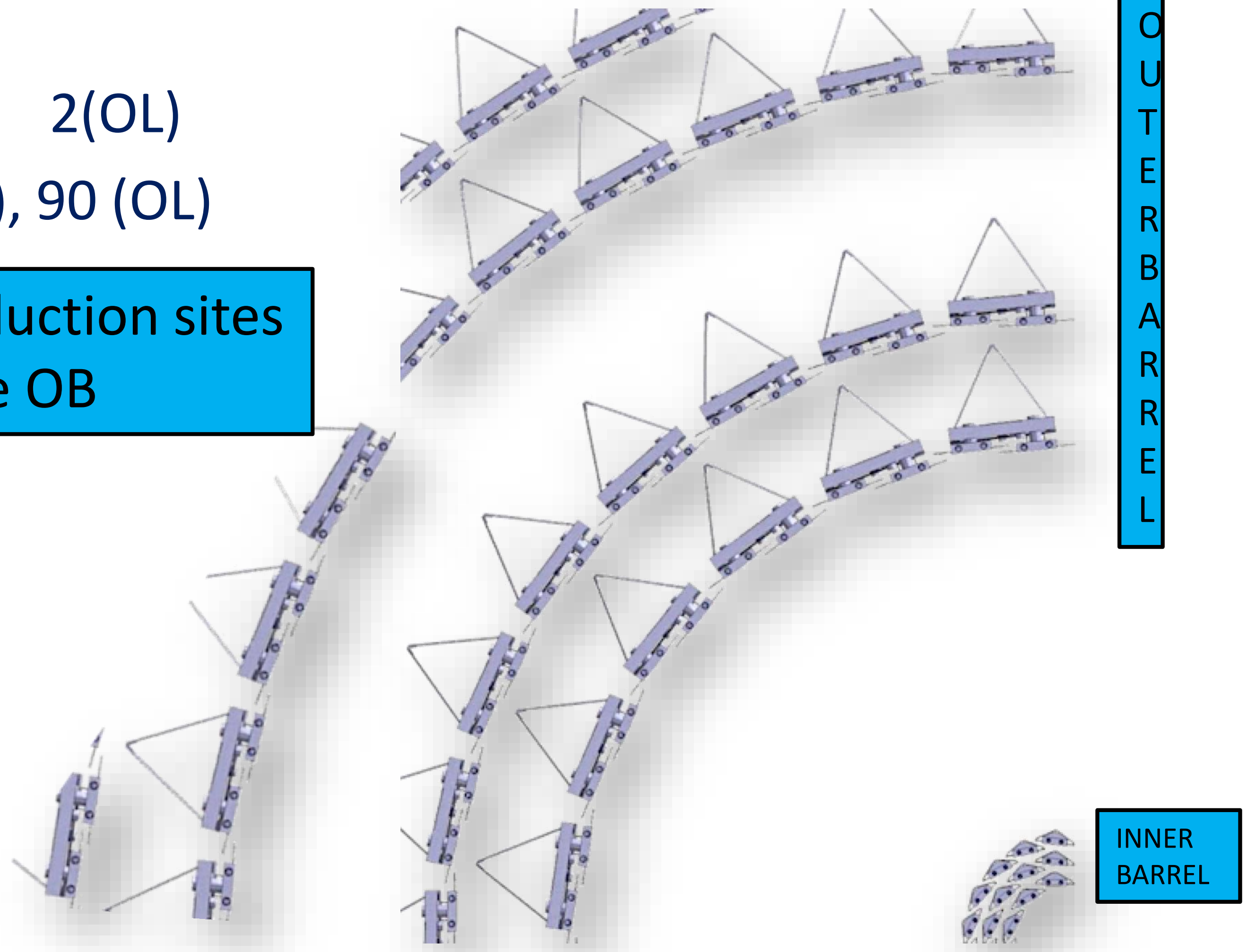
NEW ALICE ITS UPGRADE LAYOUT

The ITS comprises of

- no.7 of layers; 3 (IL), 2 (ML), 2(OL)
- no. 192 of Staves; 48 (IL), 54 (ML), 90 (OL)

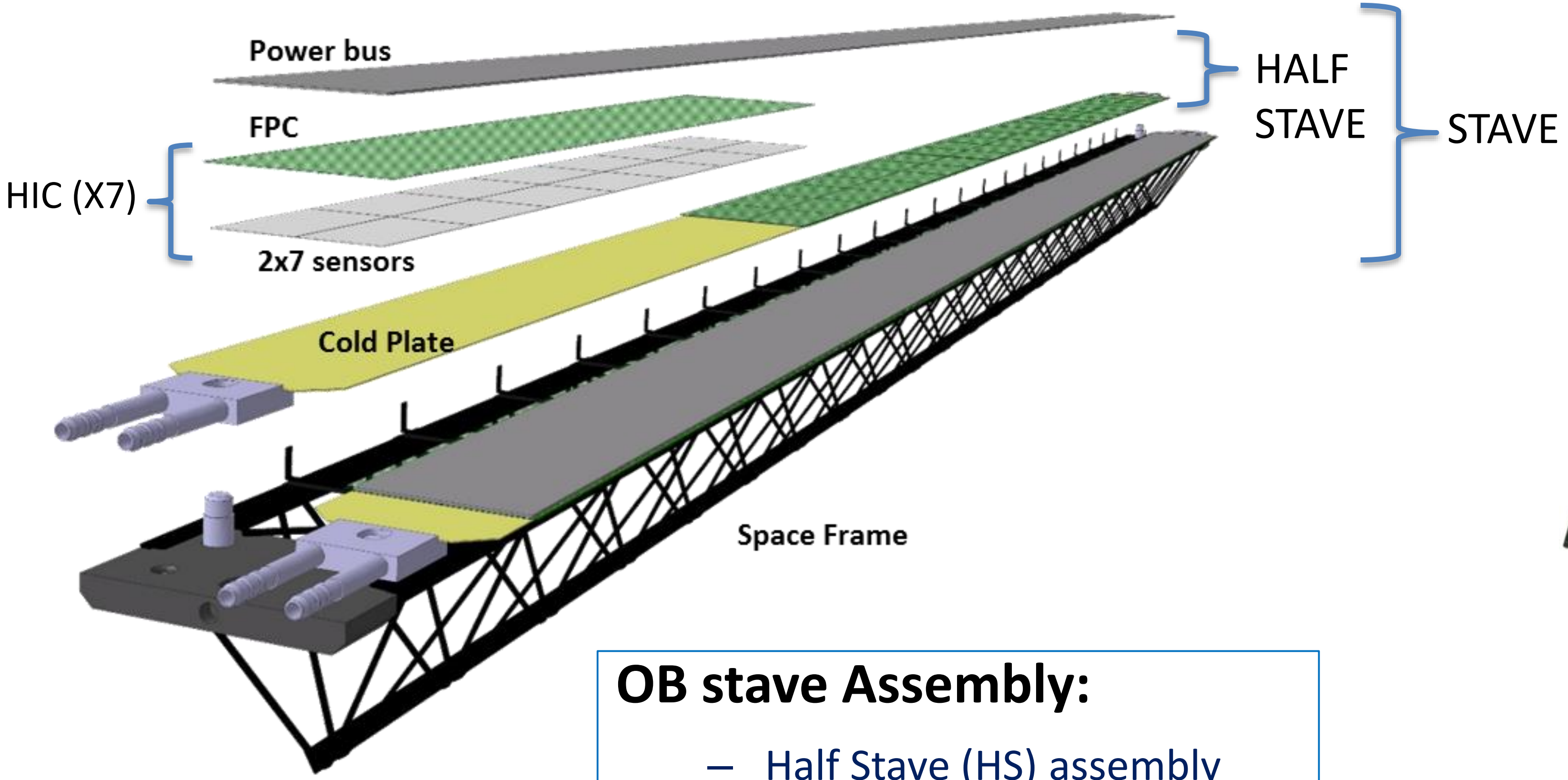
5 production sites for the OB





Layer #	6	5	4	3	2	1	0
n. of Staves	48	42	30	24	20	16	12

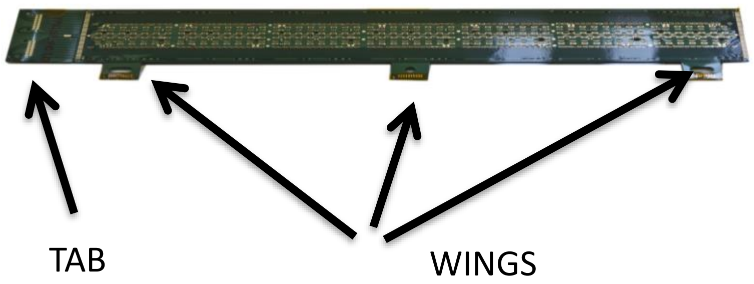
THE OUTER BARREL (OB) STAVE



OB stave Assembly:

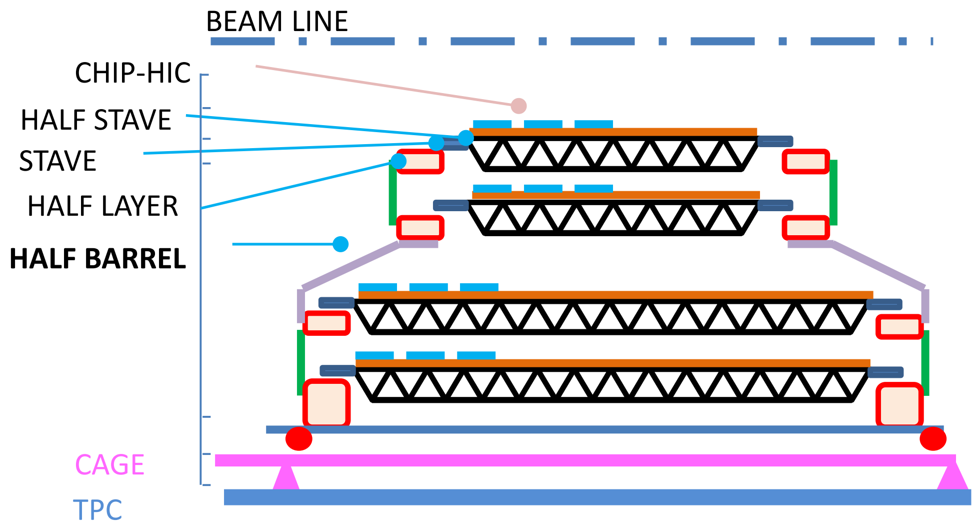
- Half Stave (HS) assembly
- Stave assembly
- Final metrology
- Power-bus soldering

HIC: Hybrid Integrated Circuit

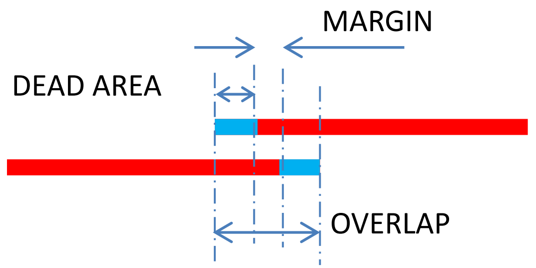


The FPC TAB and WINGS, used for HIC single test, must be cut before the HIC assembly

OB CONSTRAINTS



OVERLAP: 4245µm
DEAD AREA: 1208 µm (ALPIDE)
MIN CHIP OVERLAP: 200µm
MARGIN: 1629 µm
IN-PLANE TOLERANCE: ±815µm

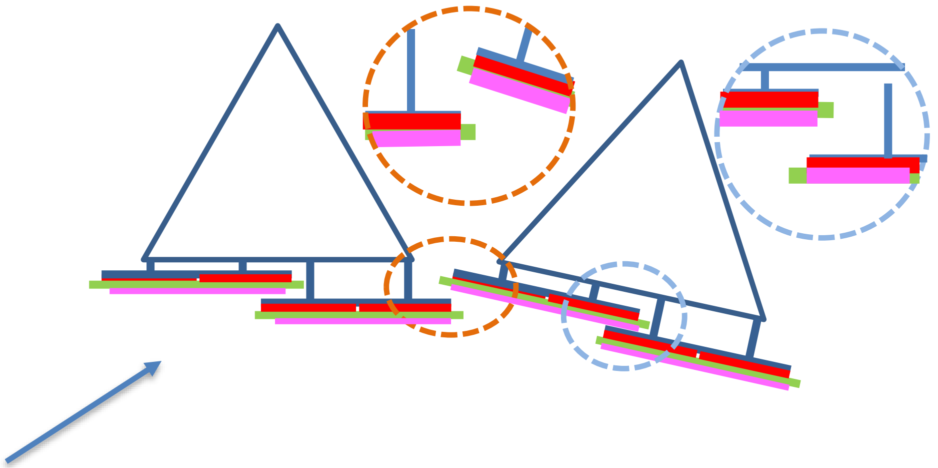


Calibration - The detector alignment based on tracks:

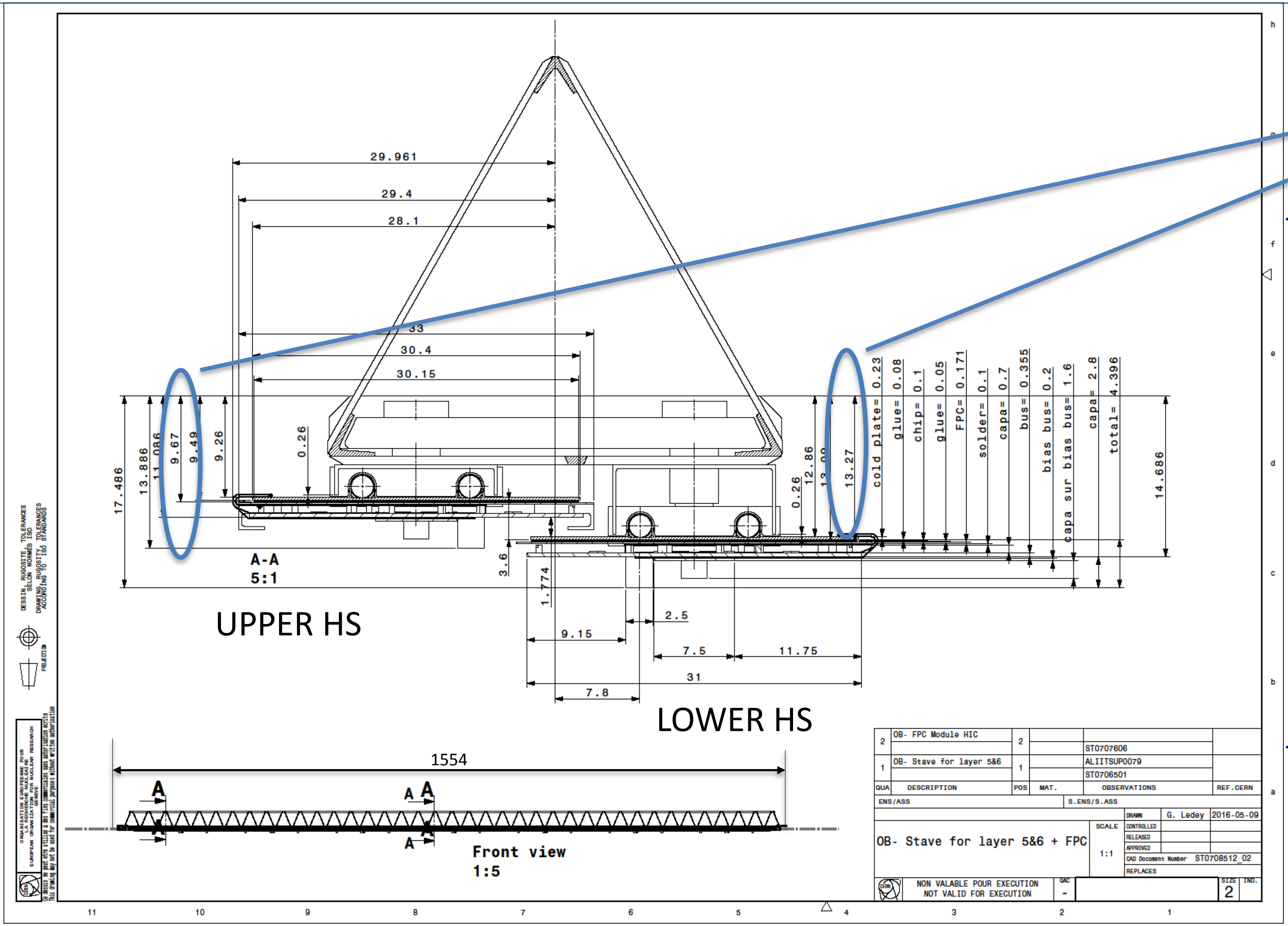
- Tolerance on the position of sensors in space < 500 µm
- Precision of initial detector alignment (by construction and metrology) < 200 µm

Hermeticity

- Longitudinal gap between active area of adjacent HIC < 200 µm
- Longitudinal gap between (active area of) adjacent chips within HIC < 150 µm
  - => Inefficiency for a 3-prong decay **~ 1.5%** (requesting hit at every layer)
- Overlap in azimuth between half-staves and staves ≥ 200 µm



OB STAVE GEOMETRY



Sensor position

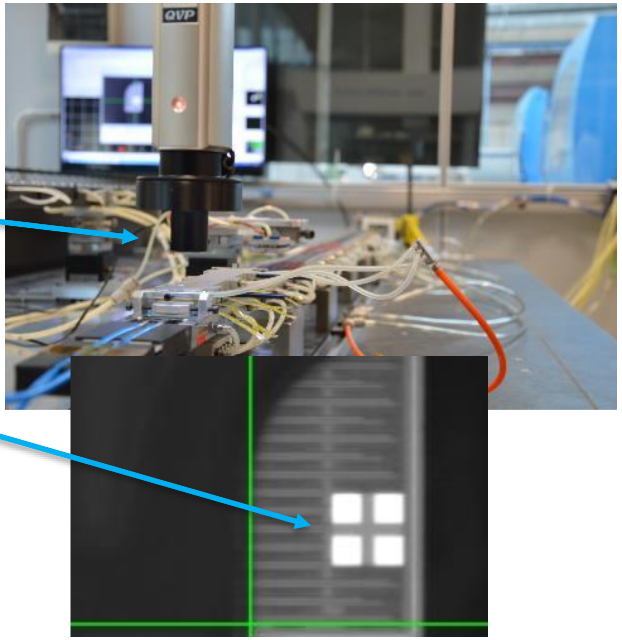
- HS layers:
  - Cold plate
  - Glue
  - Sensors
  - Glue
  - FPC
  - Capacitors
  - Bus cable
  - Bias bus
  - Capactors on bias bus
  - Capacitors on bus cable

  TOTAL THICKNESS: 4,4 mm
- STAVE layers:
  - HS gap: 3,6 mm
  - HS overlapping: 7,2 mm

THE OUTER BARREL STAVE ASSEMBLY

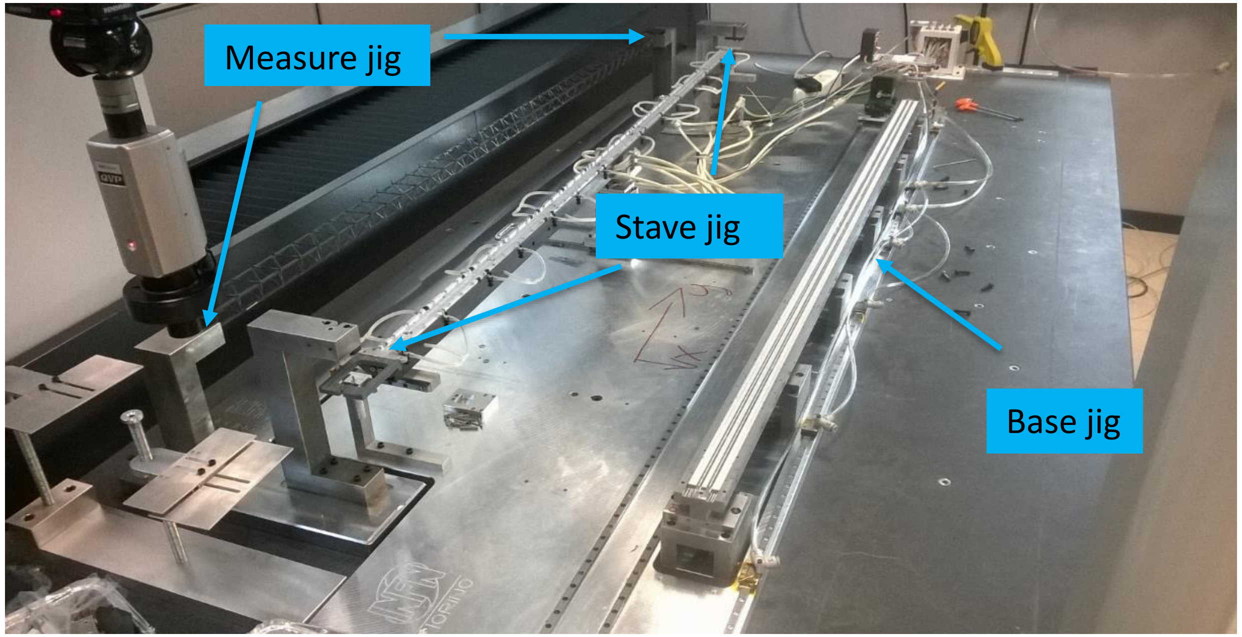
OB Stave Assembly strategy:

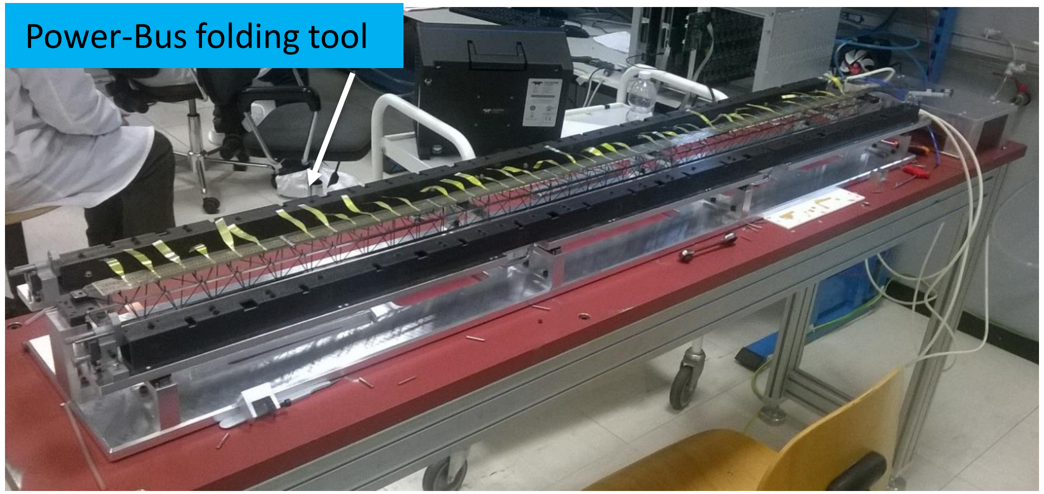
- Assembly operation under a CMM equipped with video camera, in a clean room with temperature and humidity controlled
- Reference markers on each sensor and visible through FPC holes
- definition of a reference systems for the Half-Stave and for the Stave
- definition of reference markers coordinates in the corresponding reference system
- positioning of the component in its nominal position in the reference system
- Create a data base with the metrology survey of the HIC positions after assembly
- A reference system of reference marker coordinates at all the production sites
- CMM software programs guide the operator during positioning



MODULE	A	B	C	D
MOD1	X=14,999; y=-738,575	X=14,999; y=-528,025	X=-14,999; y=-528,025	X=-14,999; y=-738,575
MOD2	X=14,999; y=-527.475	X=14,999; y=-316.925	X=-14,999; y=-316.925	X=-14,999; y=-527.475
MOD3	X=14,999; y=-316.375	X=14,999; y=-105.825	X=-14,999; y=-105.825	X=-14,999; y=-316.375
MOD4	X=14,999; y=-105.275	X=14,999; Y=105.275	X=-14,999; Y=105.275	X=-14,999; y=-105.275
MOD5	X=14,999; y=105.825	X=14,999; y=316.375	X=-14,999; y=316.375	X=-14,999; Y=105.825
MOD6	X=14,999; y=316.925	X=14,999; y=527.475	X=-14,999; y=527.475	X=-14,999; y=316.925
MOD7	X=14,999; y=528,025	X=14,999; y=738,575	X=-14,999; y=738,575	X=-14,999; y=528.025

THE OUTER BARREL ASSEMBLY MAIN JIGS





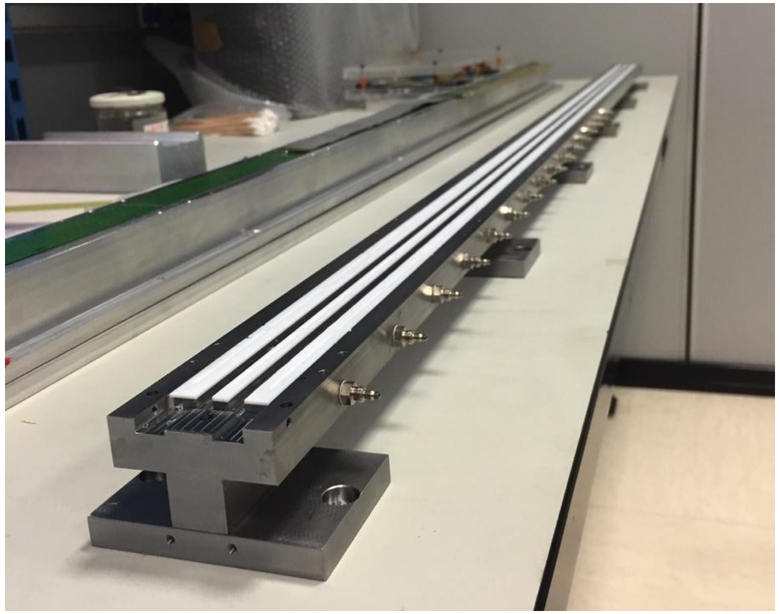
The main assembly jigs

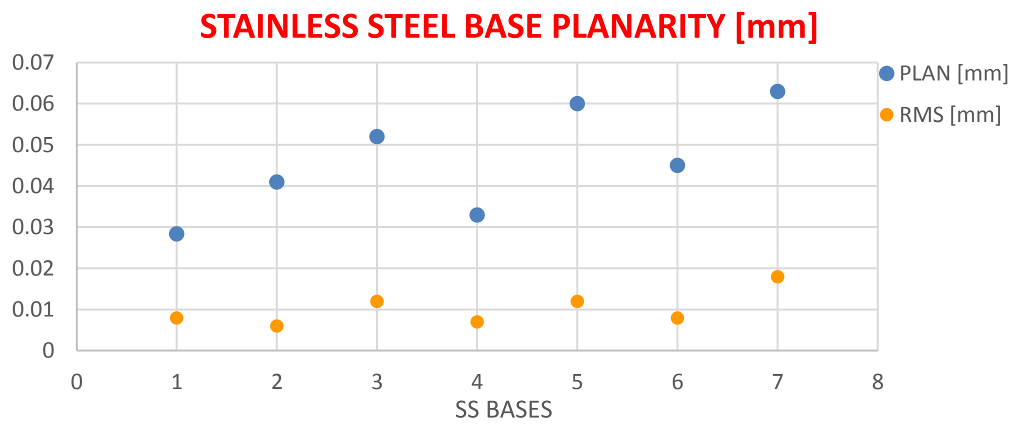
- The Base jig: for the HIC positioning and gluing on the cold plate.
- The Stave jig: for the Half-Stave assembly and gluing to the Space-frame
- The Measure jig: for the final Stave metrological survey
- The Power-Bus folding tool: for the PB soldering and folding on the Stave

THE BASE JIG

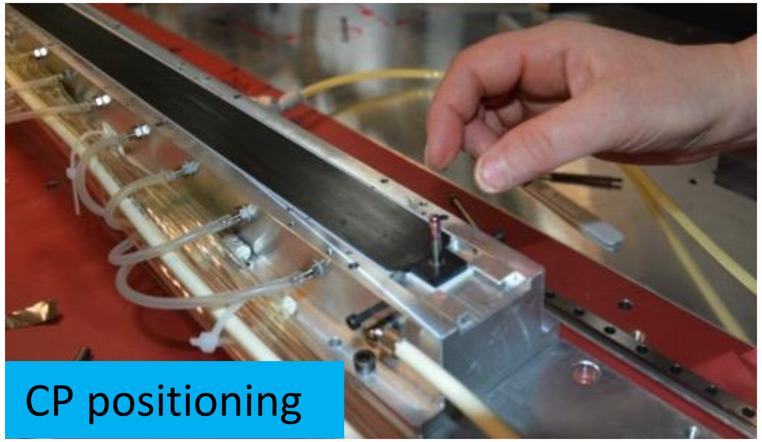
The Base Jig:

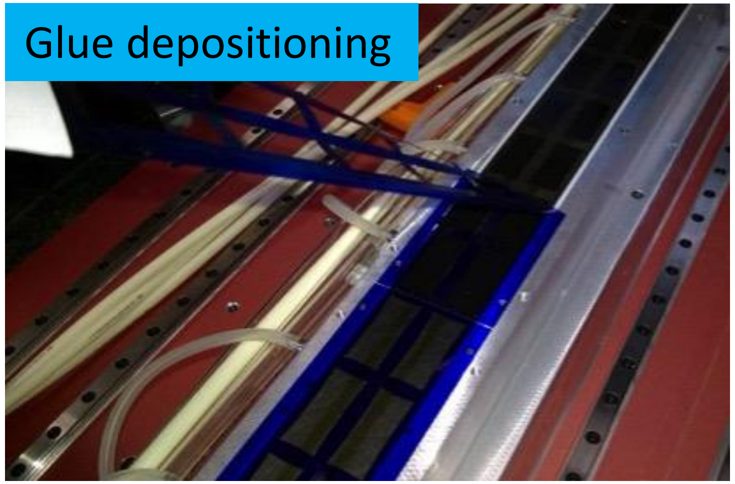
- JIG for the Half Stave assembly
- Used as
  - Cold Plate support, in carbon fiber with integrated kapton cooling pipes
  - Reference for XY plane
- Material AISI 410 + Teflon (length 1530 mm)
- Machining precision:
  - Planarity < 60μm
- Equipped with vacuum for holding CP in place
- allocates all the HS assembly and the HIC soldering tools
- Removable to allow the HIC to HIC interconnection under the microscope and the HS test

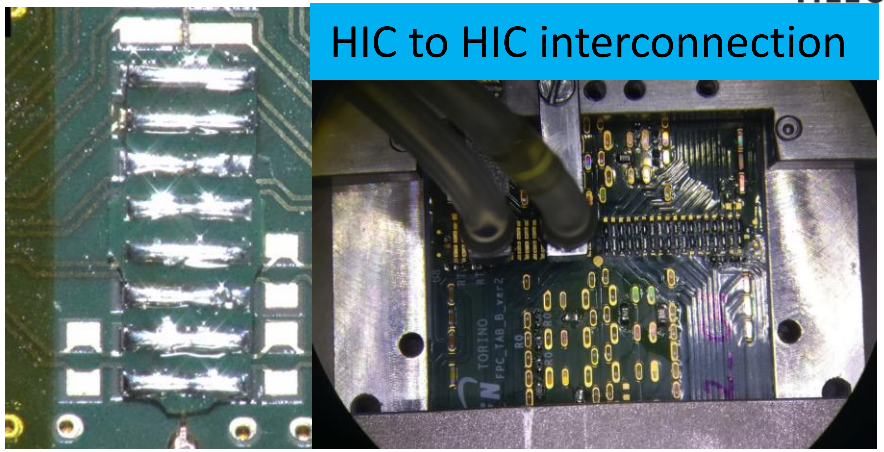




THE HALF STAVE ASSEMBLY JIG – ASSEMBLY PROCEDURE

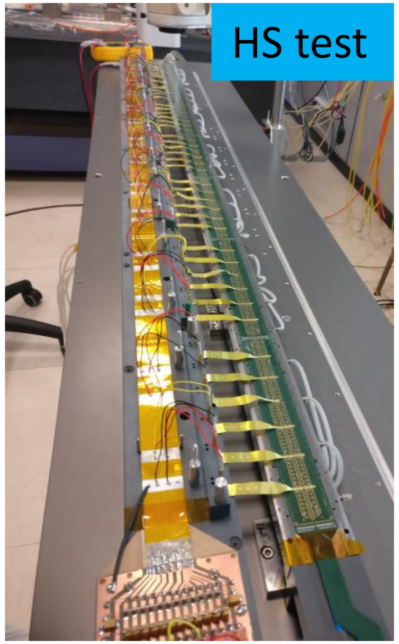

CP positioning

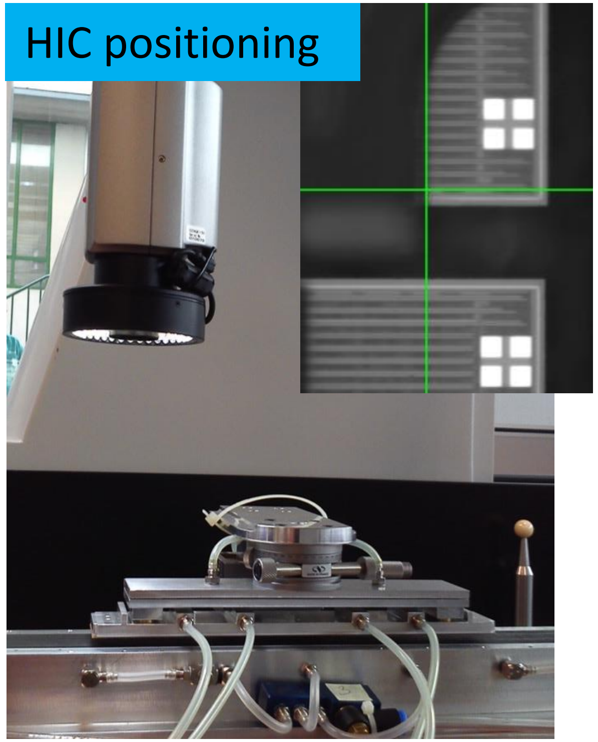

Glue depositioning


HIC to HIC interconnection

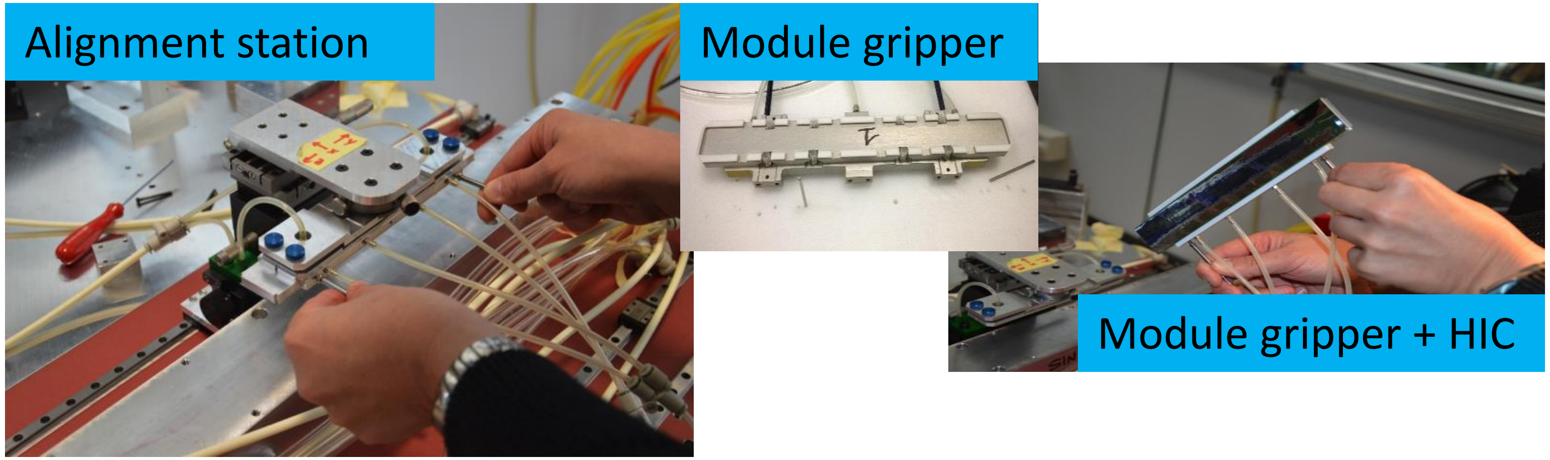
HS Assembly MAIN STEPS on the Base jig:

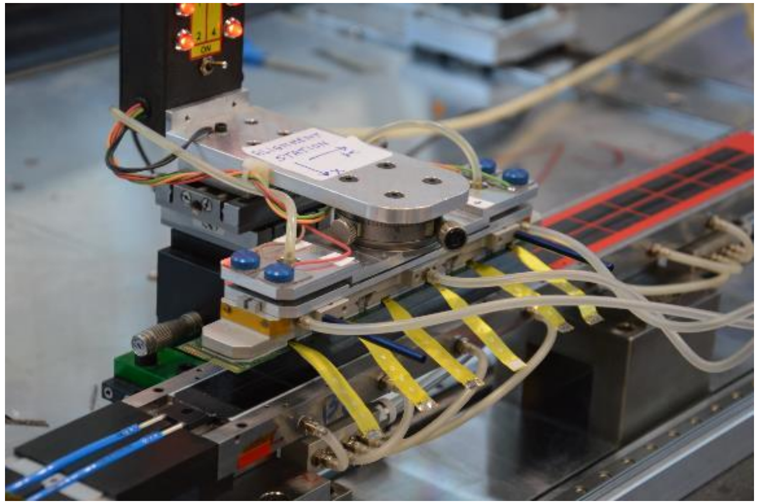
- Cold Plate positioning
- Glue deposition
- HIC positioning (X 7) by means of the module gripper and alignment station
- Metrological survey of reference markers
- HIC to HIC interconnection
- HS test
- U-arm positioning


HS test

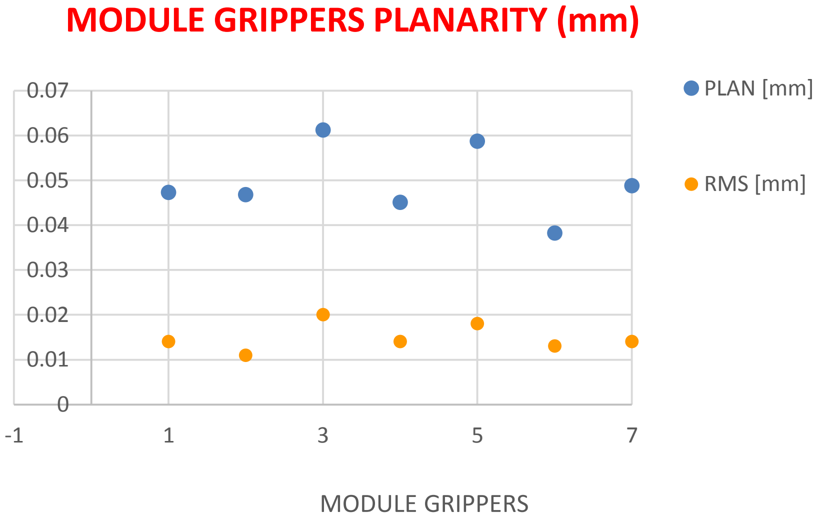

HIC positioning

THE HALF STAVE ASSEMBLY JIG - HIC POSITIONING

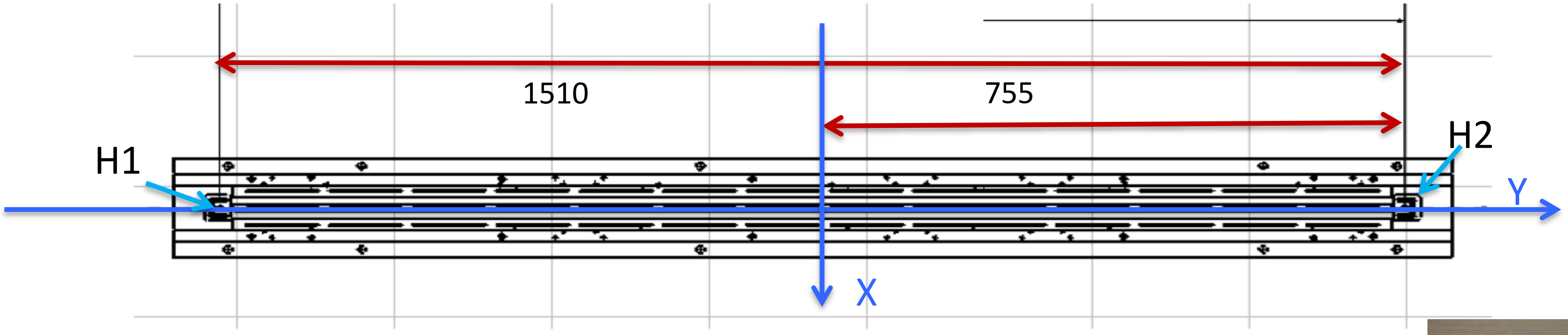




- The alignment station holds and carries the module gripper with the HIC in position under the CMM
  - Equipped with vacuum for module gripper holding, slides on rails to reach the correct position, micrometric stages allow HIC positioning precision within 10-20μm
- The module gripper, one for each HIC, holds and keeps the HIC in position during the glue polymerization.
  - Made from Alcaplus and Teflon, it is equipped with vacuum suction cups designed to be able to grip the HS from the top side without damaging the HIC.
  - The precise machining in planarity allows to guarantee good HIC flatness
- The procedure to assemble the HS on the base is guided by CMM semi-automatic programs.



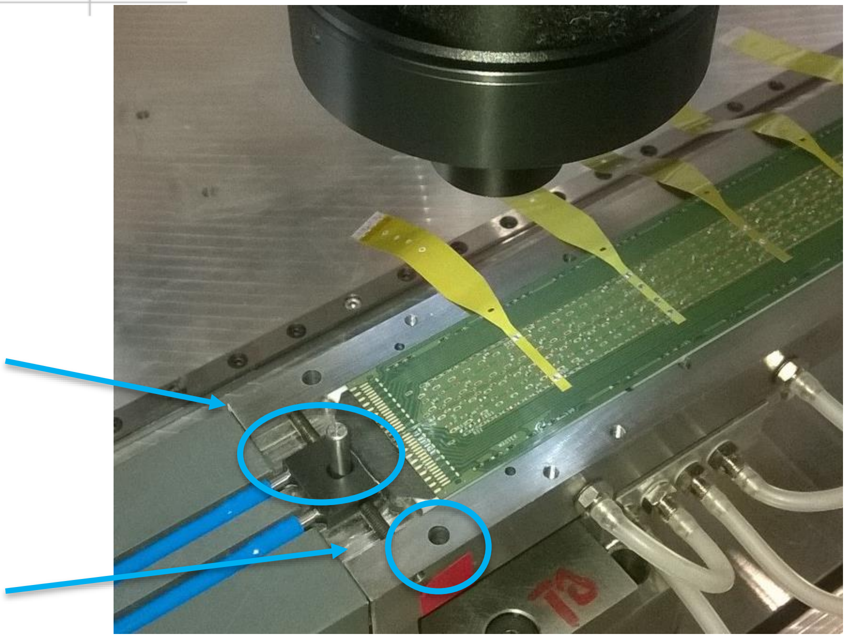
THE HALF STAVE ASSEMBLY JIG – REFERENCE SYSTEM



Half stave Reference System

— Ideal reference system for the HS: Y axis = line connecting the two pin Holes (center of the HS). Y=0 middle point of the HS along Y
  - Z: Z=0 defined as top plane of the removable base;
  - machining precision in planarity <60μm along full stave length

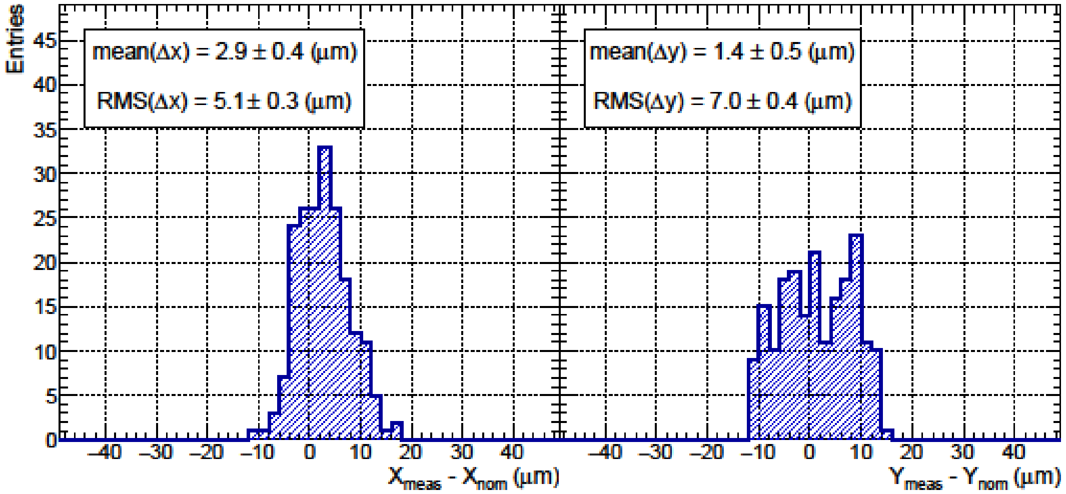
— Secondary reference system: always visible by the video camera during the assembly.
  - CMM dedicated programs work in the ideal reference system through the secondary reference system.

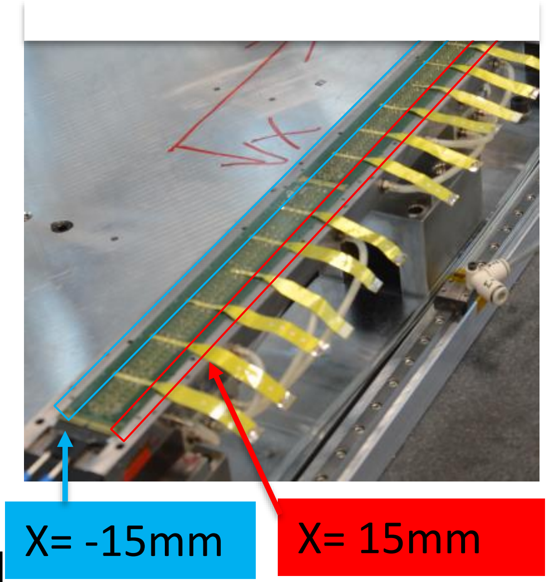


HALF STAVE POSITIONING RESULTS: example

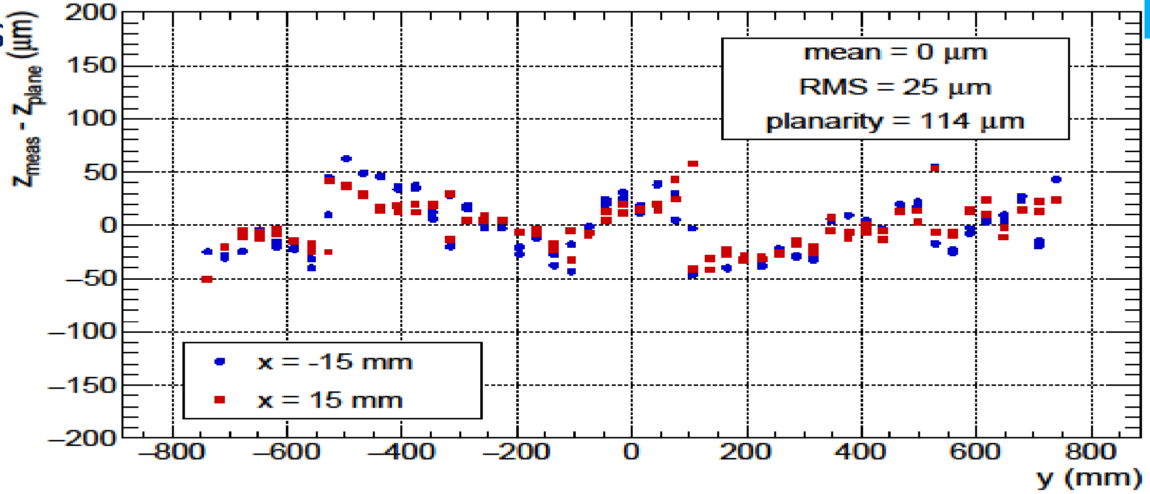
Metrology survey results of the visible markers on HS

- RMS of residuals with respect to nominal values in x and y
  - RMS well below 20μm





- Planarity and RMS of residuals with respect to XY plane
  - RMS values well below 50μm

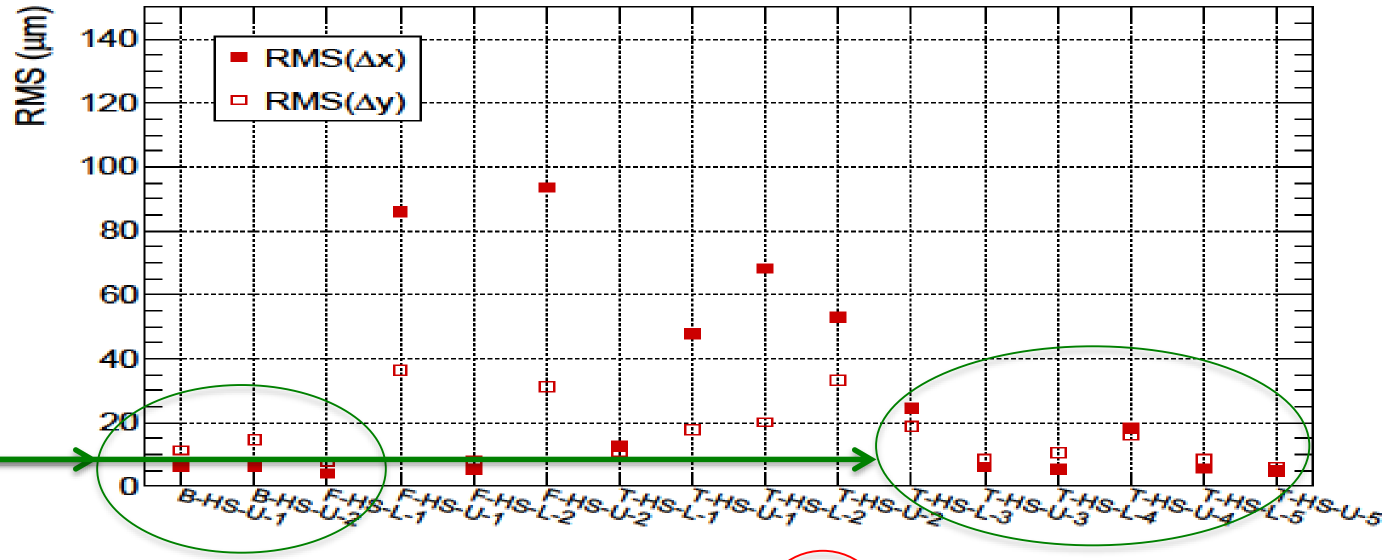


- 196 visible sensor markers at this assembly step

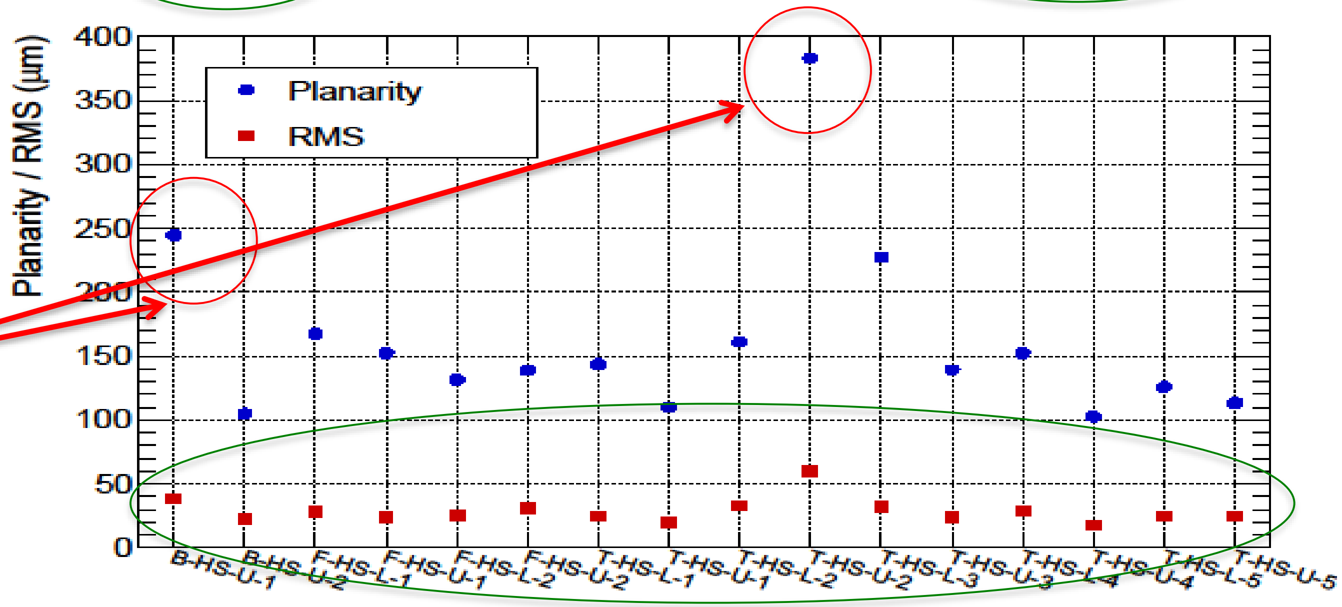
HALF STAVE POSITIONING RESULTS

Metrological survey results on the HS produced so far at production sites:

- RMS of residuals with respect to nominal values in X and Y
  - RMS well below 30µm in latest productions
  - outliers due to specific issues during first assemblies



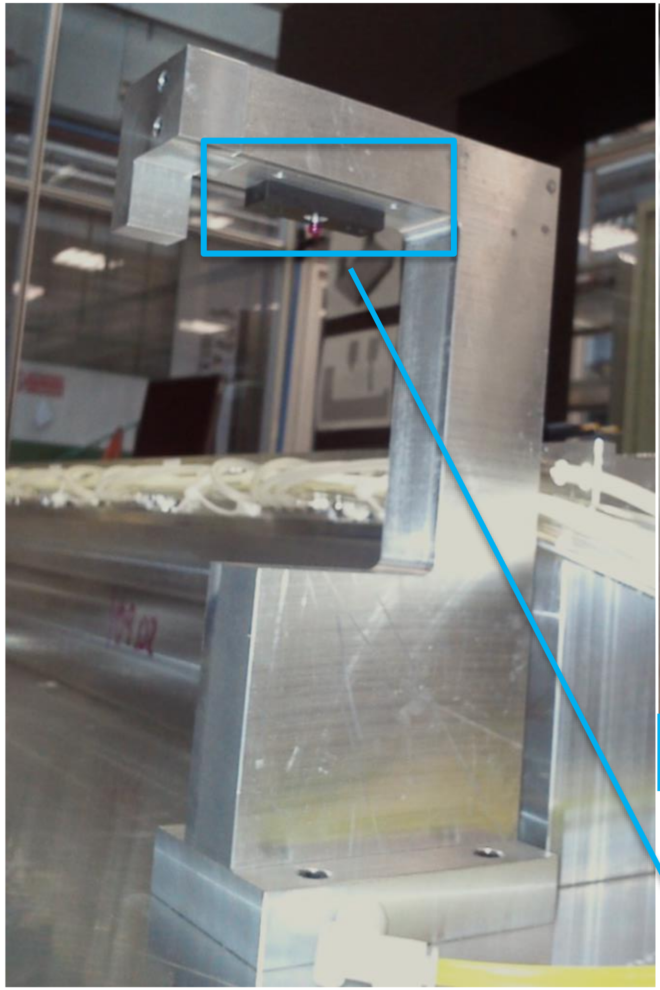
- Planarity and RMS of residual with respect to nominal values in Z
  - Z RMS well below 50µm
  - few outliers due to local defects

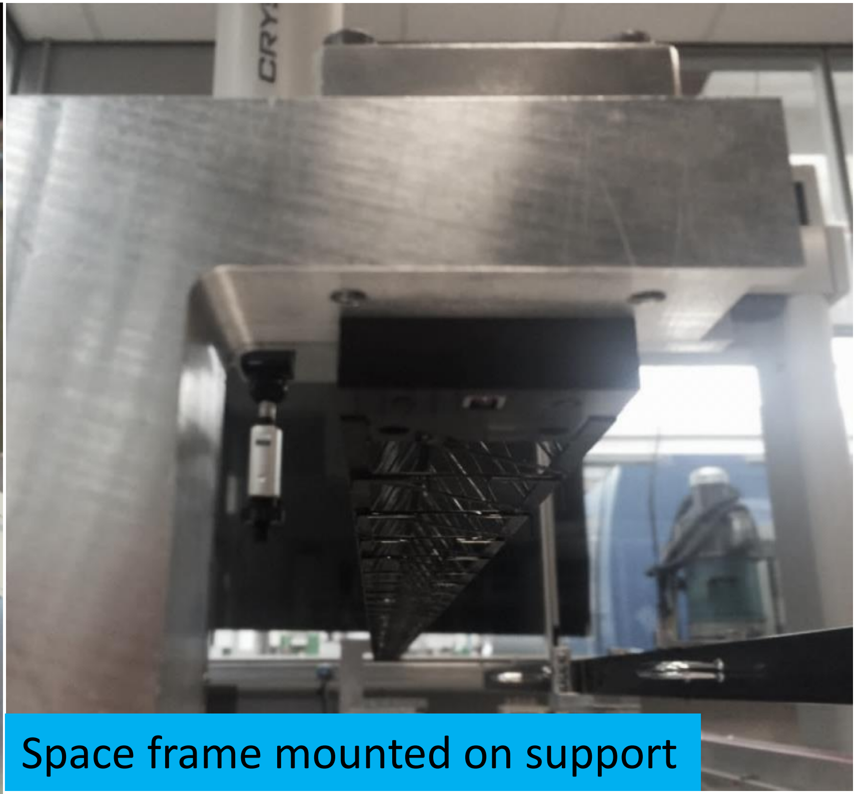


THE STAVE JIG

The stave Jig:

- JIG for the space-frame support and reference system during assembly
- Material: STAINLESS STEEL
- Equipped with ruby pads
- Ruby pads placed in position with reference mask
  - Same reference mask used in all the production sites
  - Same ruby pads used as stave supports and reference system in the ALICE ITS

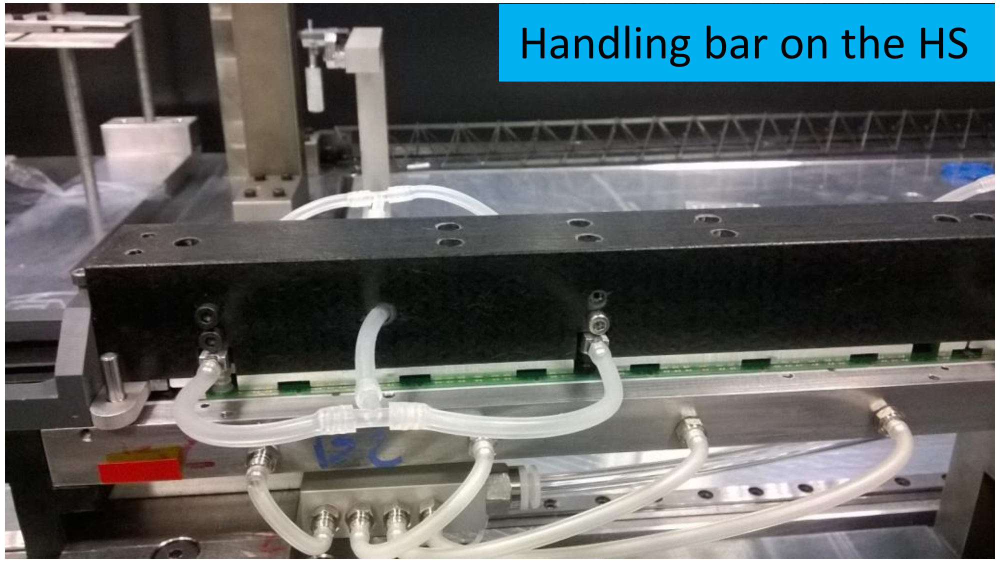




Space frame mounted on support

ruby pads + ruby sphere

THE STAVE ASSEMBLY JIG – STAVE ASSEMBLY PROCEDURE


Handling bar on the HS


HS flipping

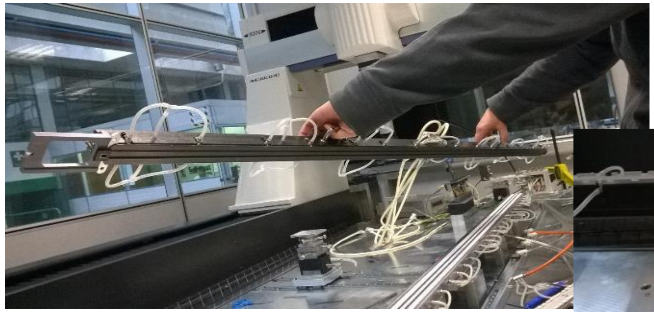
Stave Assembly MAIN STEPS:

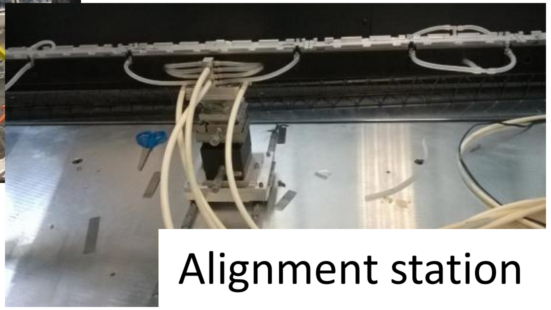
- FPC pad metrology
- Handling bar positioning on the HS
- HS rising and flipping
- HS positioning under the space frame guided by CMM programs
- HS gluing to the space frame through U-legs
- Safety pins gluing
- Planarity check and metrology


U-legs gluing

THE STAVE JIG – HALF STAVE POSITIONING

Handling bar grippers

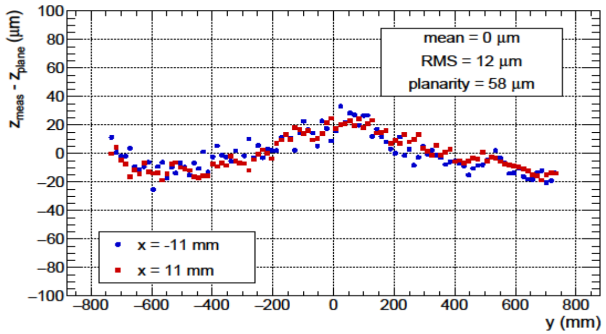




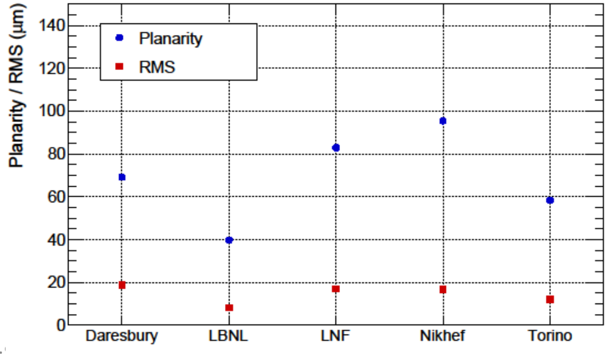
Alignment station

- The Handling Bar (HB) allows flipping the HS and placing it under the space-frame
  - Made from carbon and alcaplus (1510 mm long), it is equipped with precisely machined grippers and vacuum suction cups designed to be able to grip the HS from the top side without damaging the HIC.
  - the precise machining (~100 µm) allows to guarantee a good flatness of the whole HS
- After flipping the HB is placed on an alignment station which allows micrometric positioning of the HS under the space-frame
- The HS is glued to the space-frame through U-legs
- The procedure to position the HS under the space-frame is guided by CMM semi-automatic programs.

HANDLING BAR PLANARITY [µm]



in Turin

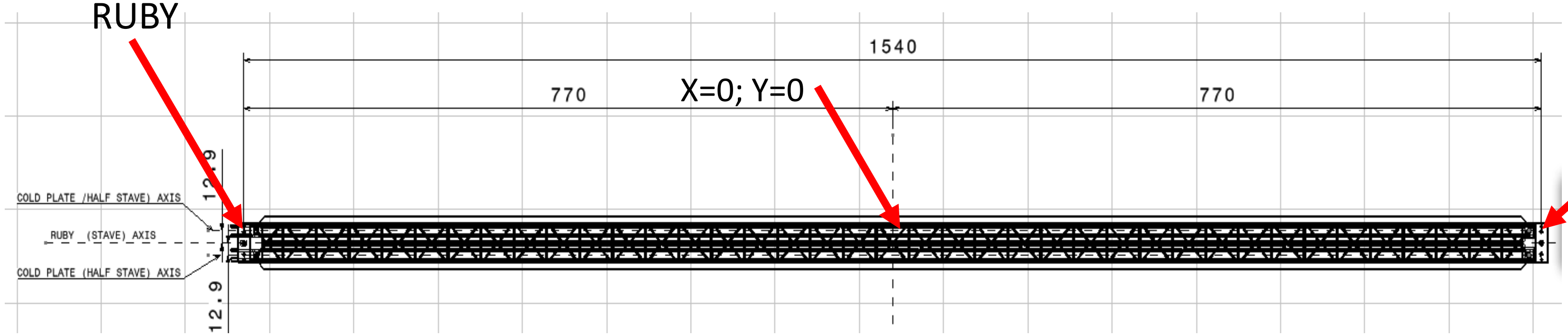


in all assembly sites

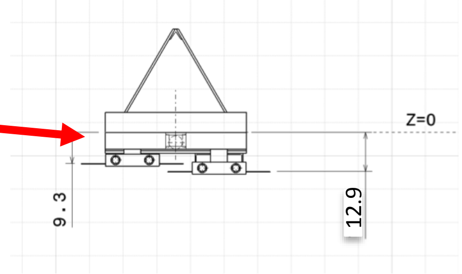
THE STAVE JIG – REFERENCE SYSTEM

RUBY

X=0; Y=0

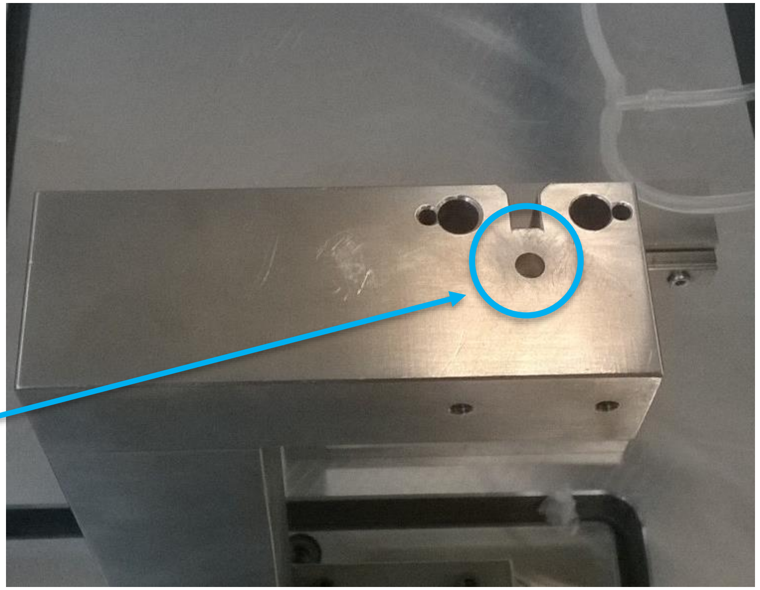


RUBY



Stave Reference system

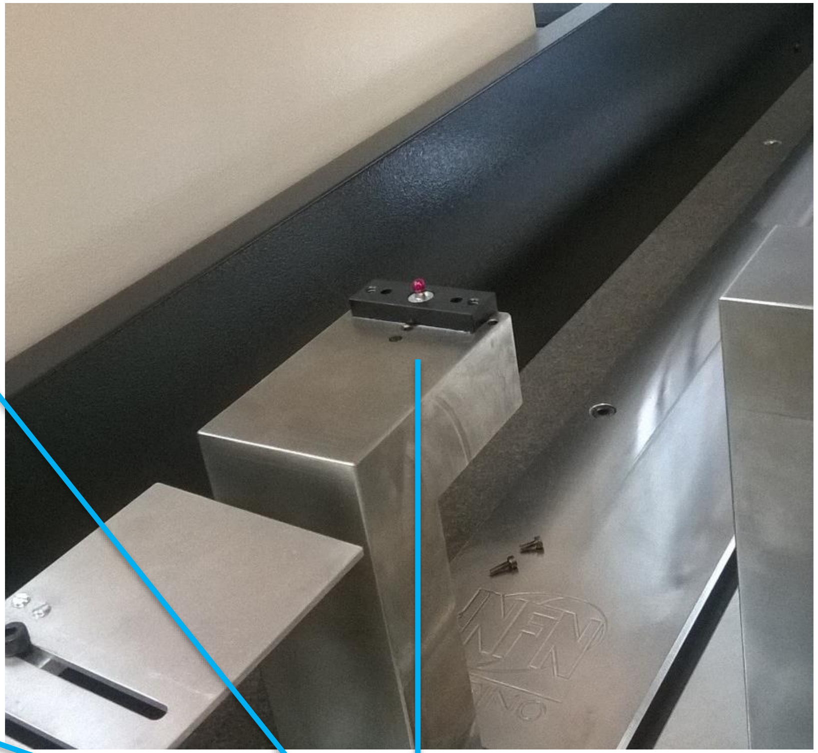
- Ideal reference system for the Stave: Y axis = line connecting the rubies (center of the Stave). Y=0 middle point of the stave along Y
  - Z: Z= 0 defined by measuring the planes of each ruby pad on both sides and taking the average plane between the two
- Secondary reference system: always visible by the video camera during assembly.
  - CMM dedicated programs work in the ideal reference system through the secondary reference system.

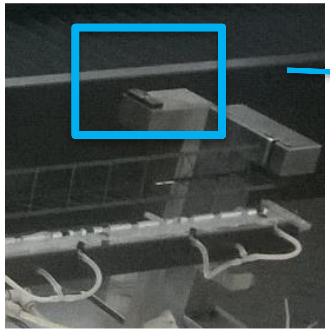


THE METROLOGICAL JIG

The Metrological JIG

- JIG for the space-frame support during metrological survey
- Material STAINLESS STEEL
- Equipped with ruby pads
- Ruby pads placed in position with reference mask
  - Same reference mask used at all the production sites
  - Same ruby pads used as Stave supports and reference system in the ALICE ITS

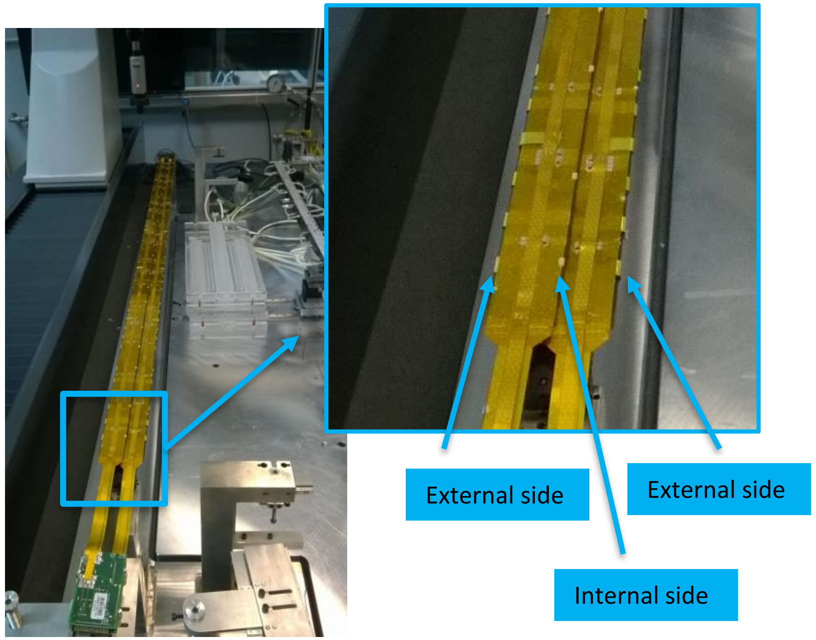




ruby pads + ruby sphere

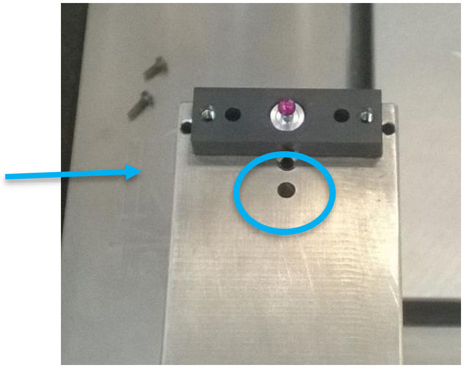
THE METROLOGICAL JIG – METROLOGY SURVEY AND REFERENCE SYSTEM

- CMM dedicated programs guide during the final metrological survey of all the visible markers.
- expected precision <15μm (video probe resolution convoluted with light effects)
- After Stave assembly:
  - LOWER HS: two reference markers for each sensor are visible (except the ones hidden by U-arms)
  - UPPER HS: two reference markers for each sensors on the external HS side are visible. The markers on the HS internal side are covered by the HS lower.



Reference system

- The ideal reference system is the same used for the stave jig
- Secondary reference system: always visible by video camera during assembly
  - CMM dedicated programs work in the ideal reference system through the secondary reference system.



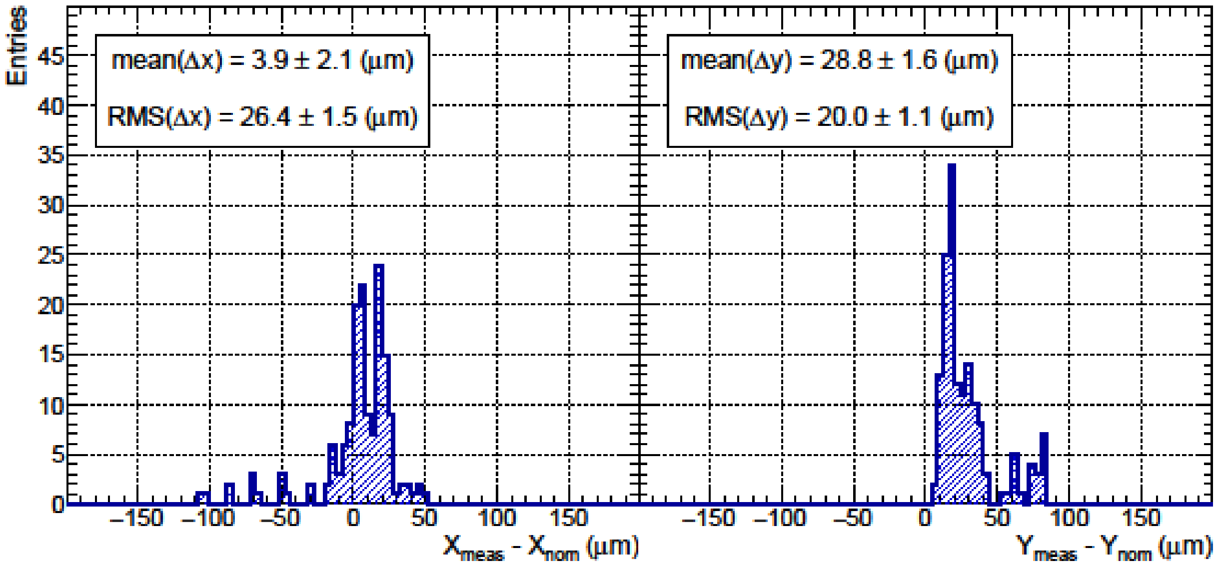
STAVE POSITIONING RESULTS: example

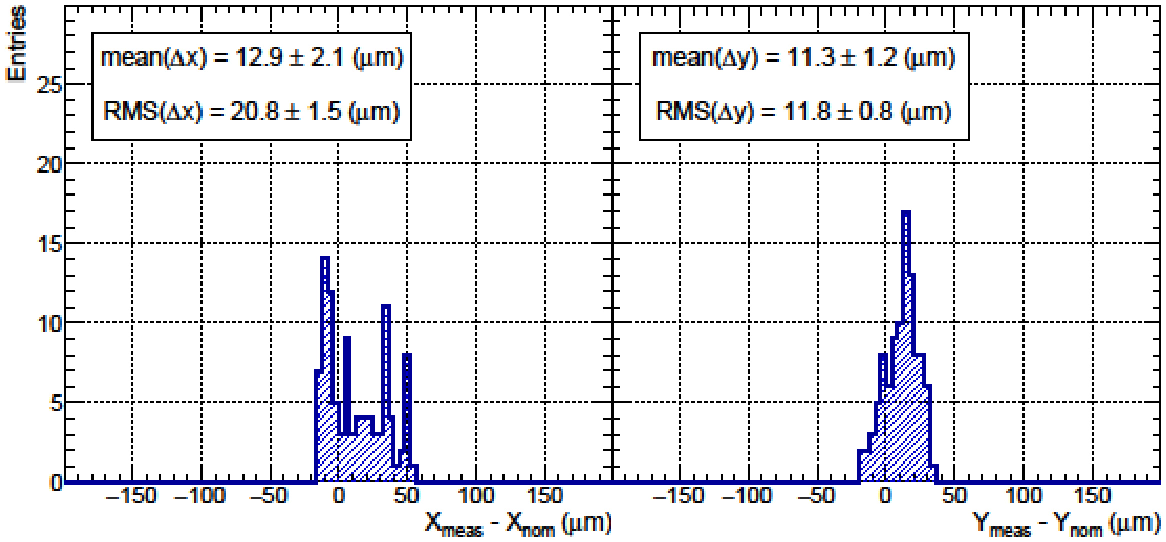
Metrological survey results of visible markers of a Stave

– RMS of residuals with respect to nominal values in x and y

  - RMS within limits

- 154 visible sensor markers of HS-L
- 98 visible sensor markers of HS-U due to overlap

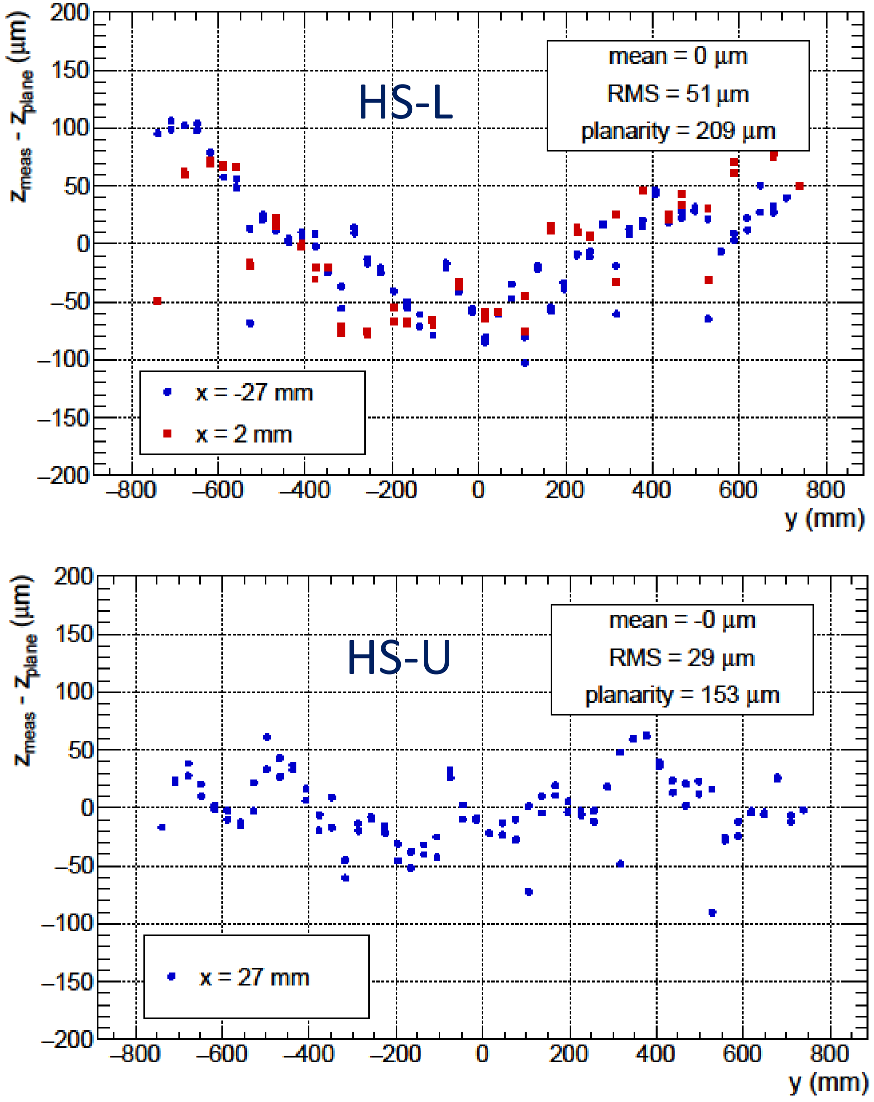


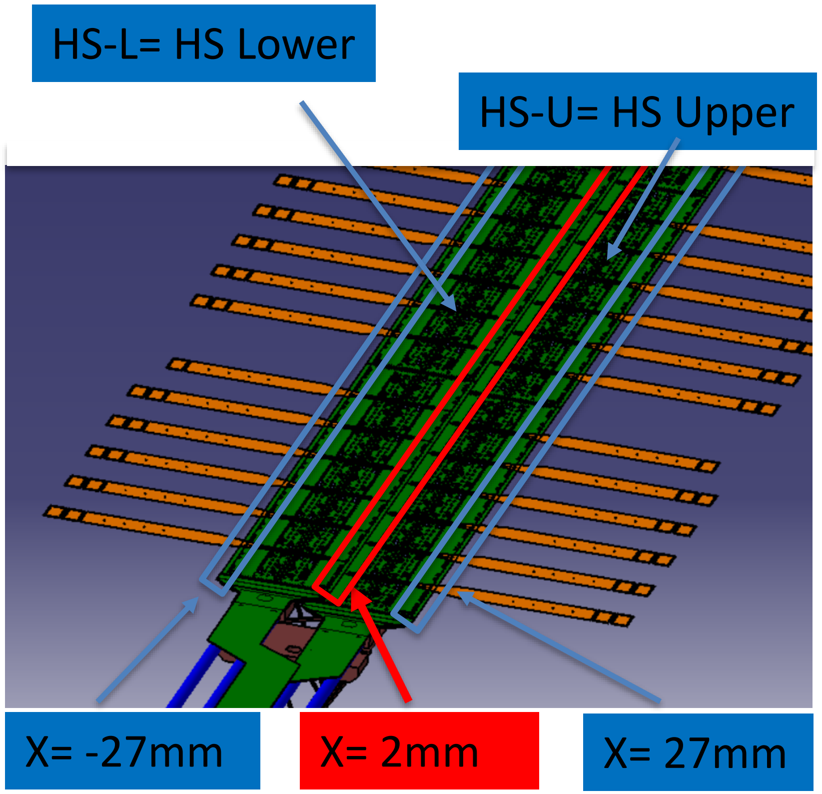


STAVE POSITIONING RESULTS: example

Metrological survey results of visible markers of a Stave

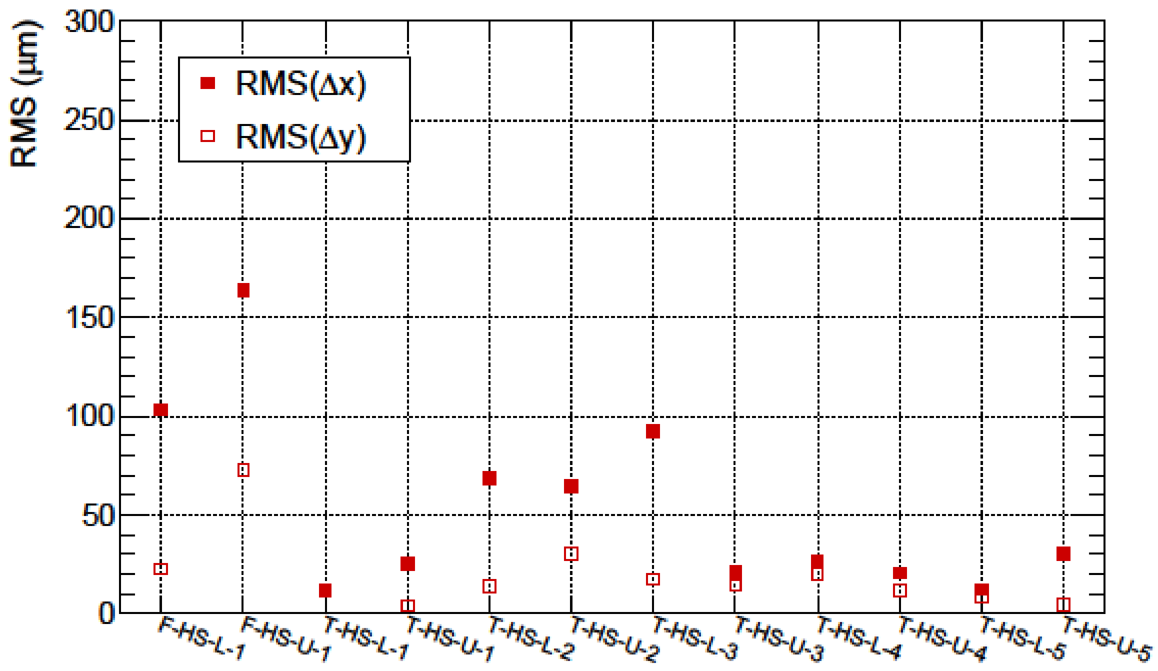
- Planarity and RMS of residuals with respect average plane for HS-L and HS-U
  - Z RMS well below 100µm
  - planarity within limits

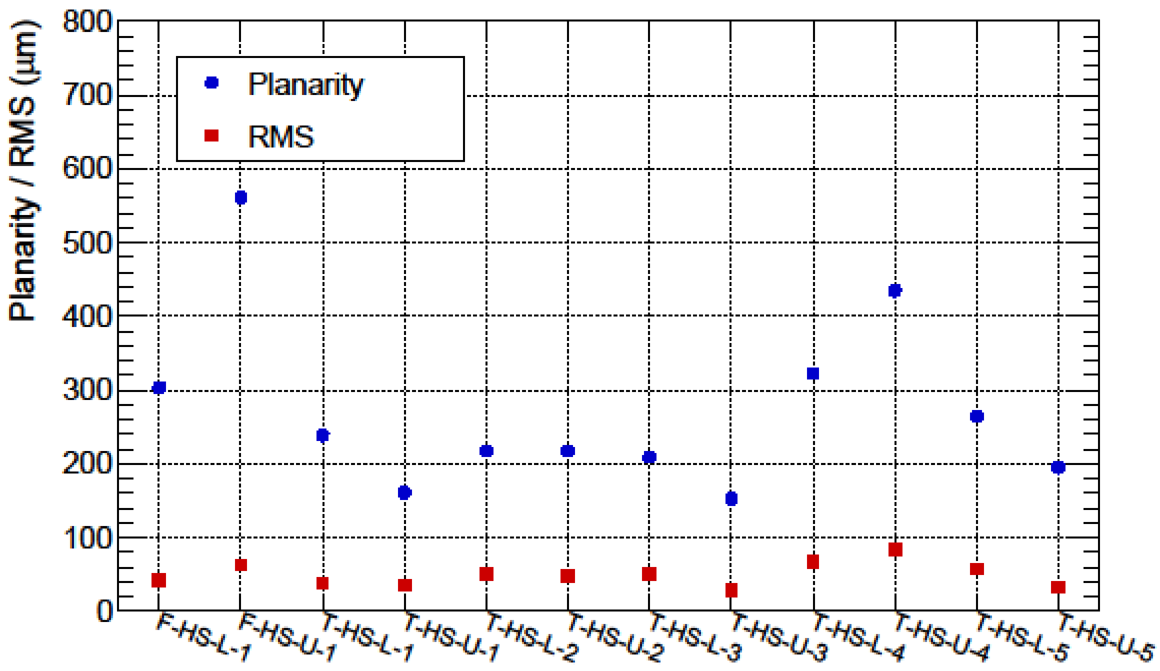




- 154 visible sensor markers of HS-L
- 98 visible sensor markers of HS-U due to overlap

STAVE POSITIONING RESULTS for Staves produced at different sites



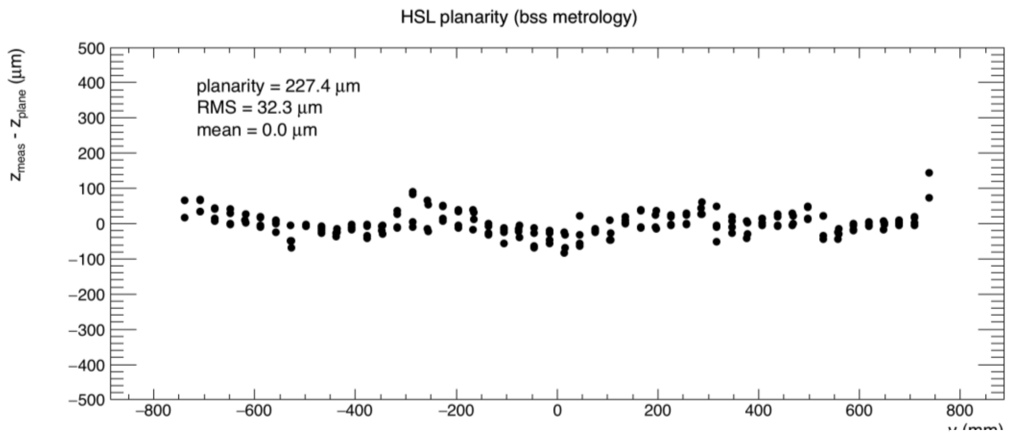


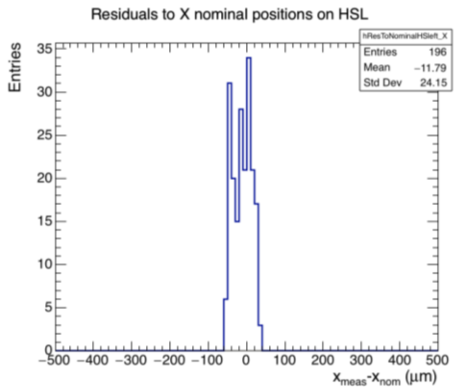
STAVE production metrology survey results at different sites:

- RMS of residuals with respect to nominal values in x, y are within tolerance
- Planarity are within limits
- some outliers due to specific issues with first assemblies

Metrology QA and hidden sensor position EXTRAPOLATION

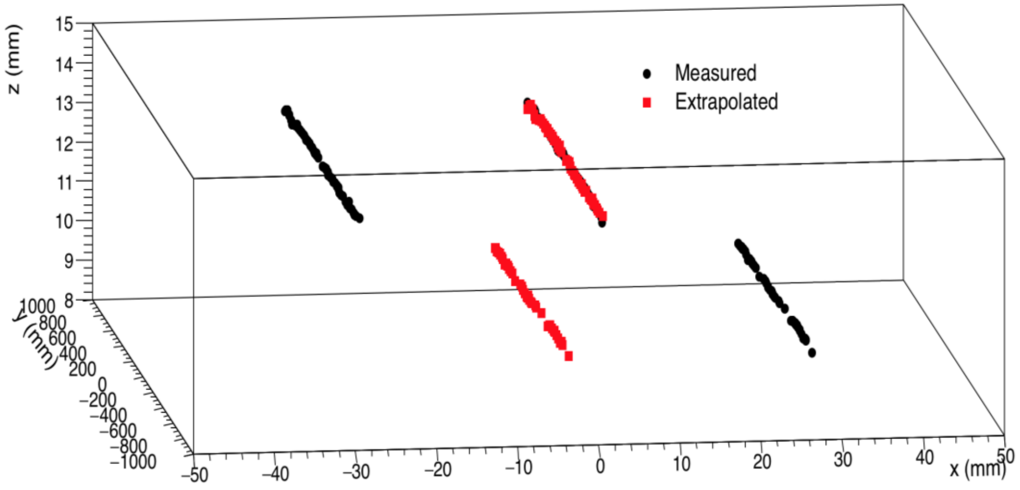
– New macro for the metrology QA and extrapolation of hidden marker position

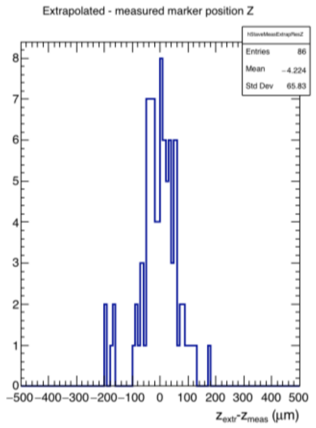




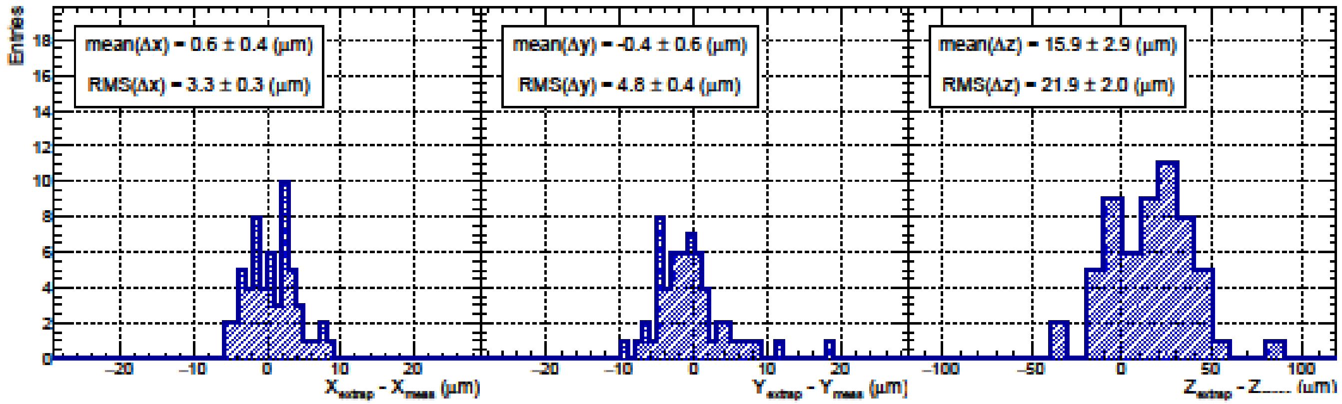
– Planarity of HS and residuals of measured sensor positions with respect to nominal ones computed for single HS and final Stave metrologies

– Hidden sensor position in the final Stave extrapolated using the information of the marker positions from the single HS metrologies
  - Goodness of procedure checked and applying it
  - RMS(x) ~ RMS(y) ~ 5-10 μm
  - RMS(z) ~ 30-50 μm





HIDDEN STAVE POSITIONING RESULTS

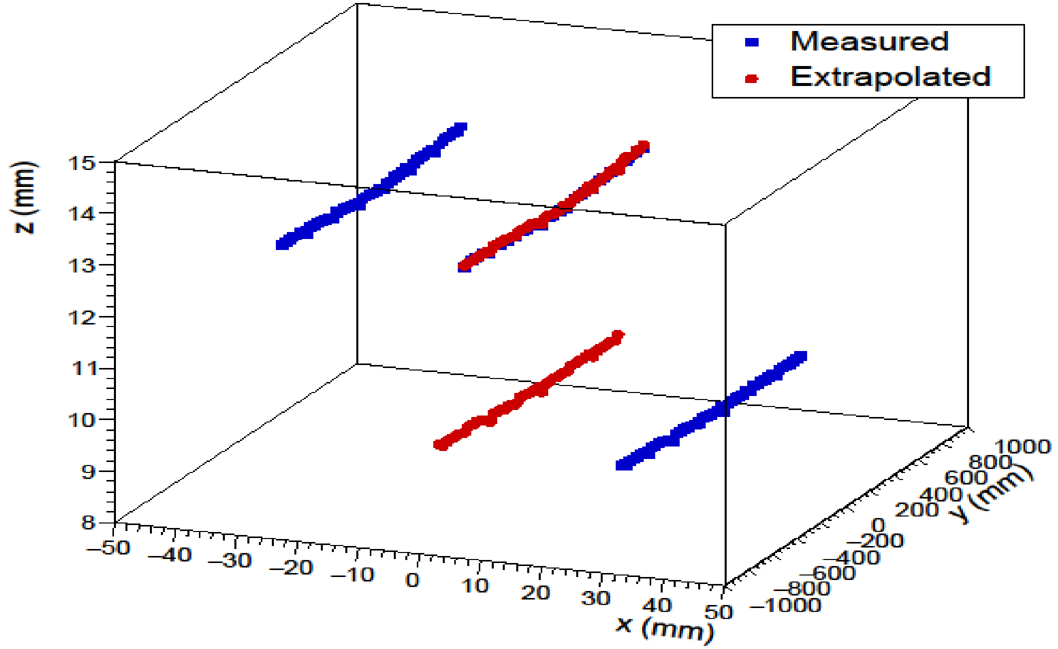


STAVE final positions

- residual distribution of the extrapolated sensor positions with respect to reference values

STAVE final position

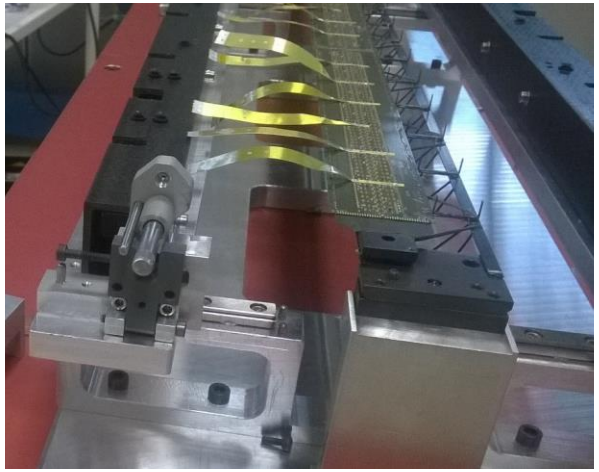
- Hidden sensor position in the Stave extrapolated using the information of the sensor positions from the single HS metrologies



THE POWER BUS FOLDING TOOL

The PB tool

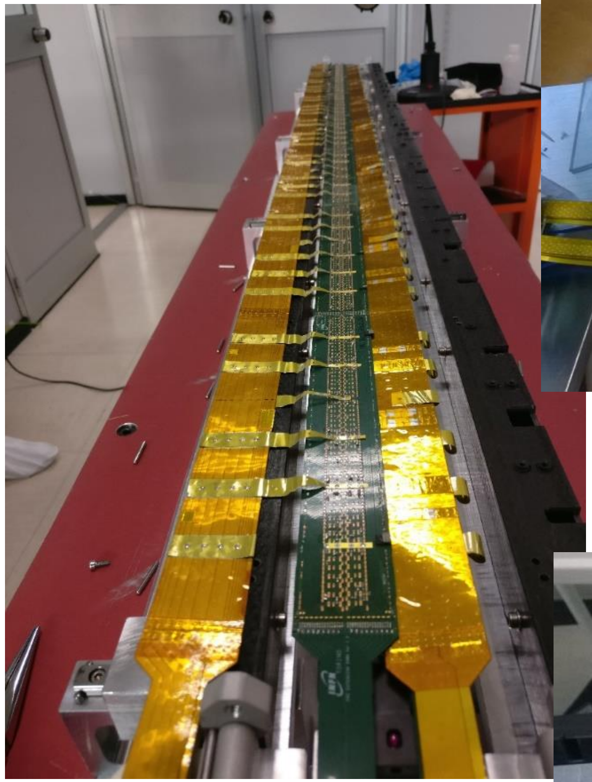
- JIG for the stave support during the PB connection, folding and positioning
- Material: carbon bar and Aluminum (length 1600mm)
- Equipped with suction cups to hold the PB in position during folding
- Station equipped with cooling circuits for stave test

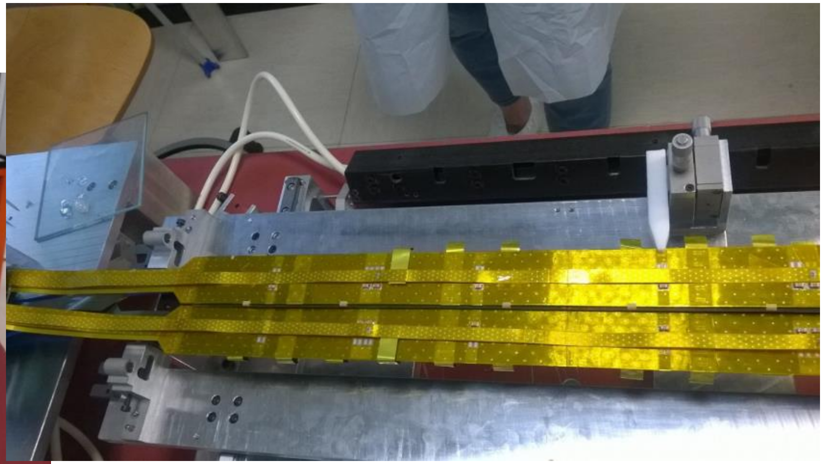


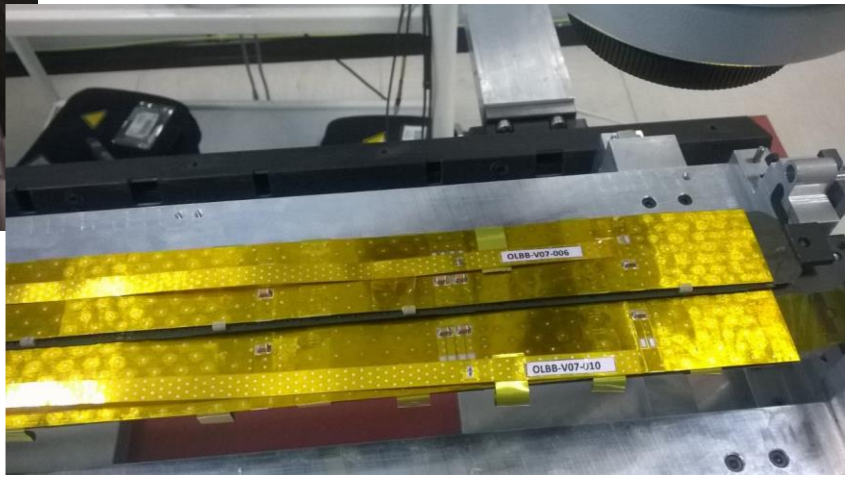
THE PB FOLDING TOOL – ASSEMBLY PROCEDURE

PB Positioning MAIN STEPS:

- PB connection to HIC Cross Cables
- HS test
- Power bus folding and positioning (X2)
- Stave test
- U-arms gluing (to keep the PB in position)
- Stave validation



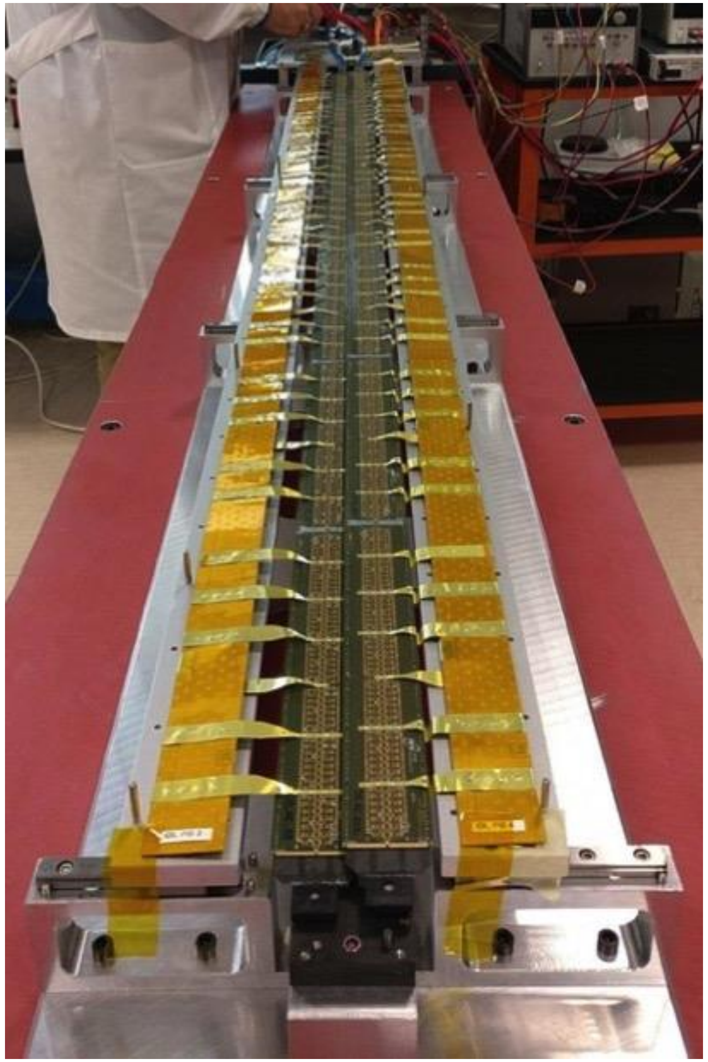




FUNCTIONAL TEST RESULTS

13 OB Staves produced so far:

- 2 ML + 11 OL
- results of tests, though preliminary, are very encouraging:
  - average working chips > 98%
  - non working chips mainly due to issues in the first phases of construction
  - latest produced Staves show 100% working chips
  - Noise and threshold values are comparable to single chip ones



CONCLUSION

- All the mechanic tools have been produced and set up for all the 5 construction sites
- The OB stave construction project has completed the R&D phase and it is now in full production phase
- Final metrological survey results are well compatible with the design requirements at all sites
- Functional test of Staves produced so far show encouraging results. The production will continue in the next months (completion expected by April 2019)

The project is well on track for installation starting middle 2020