Developing a Glue Robot for ITk End-Cap Strip Module Assembly

A Dive into Applied Glue Science

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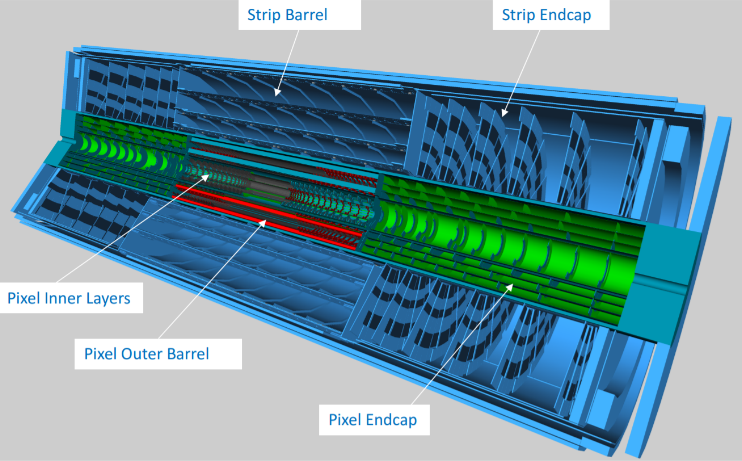
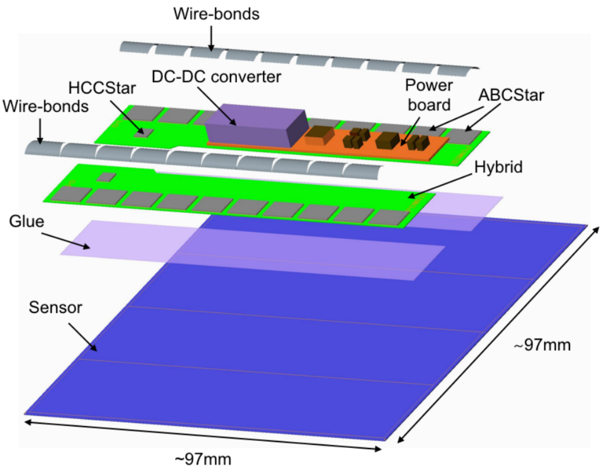
The ITK detector

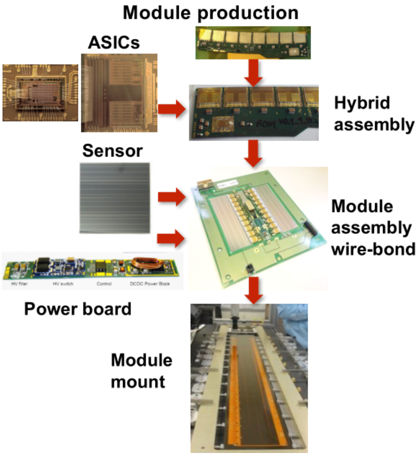
The new Inner Tracker (ITK), is an all silicon tracker - divided into subsystems based on sensor type and mechanical support structure.



Module composition



Blow-up of barrel-type module



Module assembly in the Scandinavian Cluster

- The ITk will consist of ~ 19000 independent detector modules.
- Scandinavia will produce ~ 600 modules of three different geometries.
- Required production yield $\geqslant 98$ % at every step of assembly.
- This talk focuses on the ”Module Assembly” part of the process.

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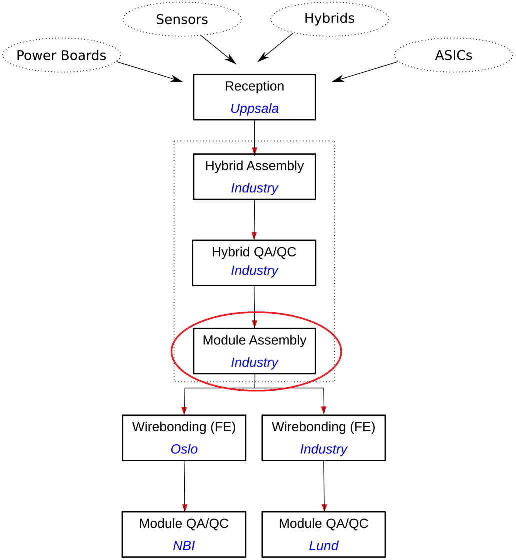


Collaborating with Industry

Baseline is to carry out productions in-house - but:

Scandinavia and a few others will collaborate with industry for the module production.

Primary reasons for this:

- We don’t have the in-house manpower for undertakings of this scale.
- We find it valuable for the instrumentation community to exercise industry collaboration.
- Why re-invent the wheel - investing in production infrastructure already existing in industry?

Optimising assembly procedures for industry workflow

- Collaboration baseline assembly procedures rely heavily on manual labour approaches - eg. gluing components by hand, using stencils.
- Scandinavian Cluster are collaborating with electronics company specialising in automated production flow.

So, we need to re-develop assembly procedures, into more automated approaches better suited for the work flow in industry

Requirements for hybrid-to-sensor mounting

height of glue layer $z = 120 \pm 40\ \mu m$

- Too thick = unnecessary thermal barrier.
- Too thin = more noise from capacitative coupling between sensor and hybrid

Filling factor ~ 60 %.

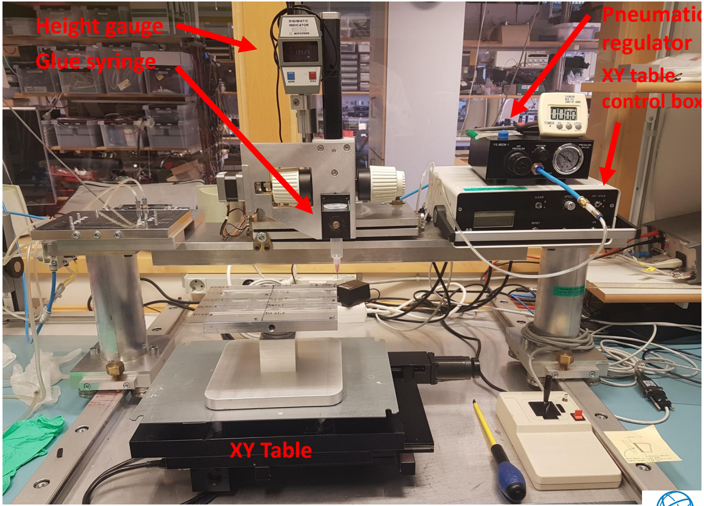
Sufficient glue coverage between hybrid and sensor for mechanical stability during wirebonding

NO glue seepage onto strip bond pads or guard ring.

- Covering the strip bond pad makes it unbondable - channel loss.
- Covering the guard ring might short-circuit the edge isolation structure - rendering the sensor useless.

In house setup

- Sensor jig on XY-table.
- Glue syringe fixed in a Z mount.
- Dispensing on/off through eletric pneumatic valve - manual pressure regulator.
- Custom Python framework controls the robot.
- Glue amount controlled by speed of XY-table.



A note on glue

The glue is qualified based on:

- Low shrinkage during curing.
- High thermal conductivity
- Sufficient bonding strength across large temperature range (-35° *C* to 40° *C*)
- Radiation hardness.

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Cannot just go to the the Hardware Store...

Only one vendor offers a viable product, a two-component epoxy, Polaris PF 7006A, (meaning expensive) - delivered to us in small pre-proportioned bags.

Challenges of Glue Robot Calibration I/II

Many variables

Fine tuning for dispensing has shown different dependencies on a number of variables.

The following variables were considered:

- XY-table speed
- Needle gauge
- Dispensing pressure
- Needle height over sensor surface

Only real way of programmatically controlling glue amount dispensed is through the XY-table speed. Other variables kept constant.

Inverse scaling between XY-table speed and dispensed mass.

Challenges of Glue Robot Calibration II/II

Time Dependency

Epoxy cures over time → viscosity increases → flowrate at constant pressure decreases → dispensed mass goes down over time, using identical settings.

Target Mass Scaling

Need to translate between a target mass of glue, and the table speed setting. This scaling changes with the viscosity of the glue.

Length Scaling

Need capability to dispense same amount of glue mass over differing lengths.

We need $V(t, m, l)$, parameterising XY-table speed w.r.t. time elapsed since mixing glue, the target mass and the desired length to dispense this mass over.

Calibration approach

- Procedure should be flexible and allow for ”easy” transition between prototyping and production type modules.
- Approach was be to split each path of the pattern into sublines off $8\ mm$, Robot calibration was done solely wrt. to this $8\ mm$ baseline.
- To optimise glue spread, small voids included between some $8\ mm$ lines.

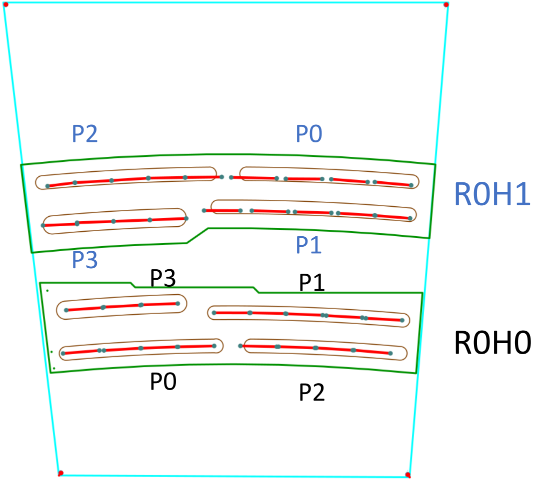


Figure: R0 sensor with its two hybrids, and the glue patterns underneath them.

Calibration approach - $V(m,t)$ look-up table

The calibration should take two input variables

- Time since mixing
- Desired glue mass

Accomplished by $V(m,t)$ Look-up Table

A fine grained scan of the dispensed mass across a range of speed settings diminishing over time.

Data was sorted into a list of lists, $V[\Delta m_i][\Delta t_j]$, with bin-width's of 1 *mg* and 1 *min*.

Originally analytical approach was attempted:

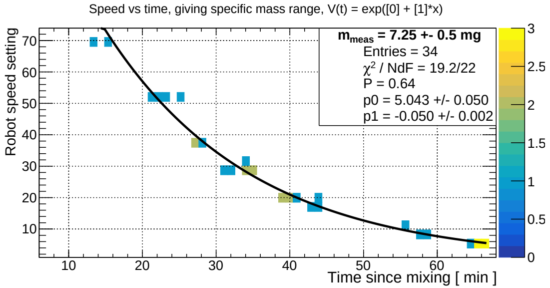
Very nice time stabilisation was achieved.

But very difficult to combine with target mass and length calibration - separation of variables not possible.

Not feasible to gain enough statistics for multi-variable fit - glue supply is limited.

$V(m, t)$ look-up table

To Fill in blank spots in the table, Fits are used to interpolate values. two examples shown below.



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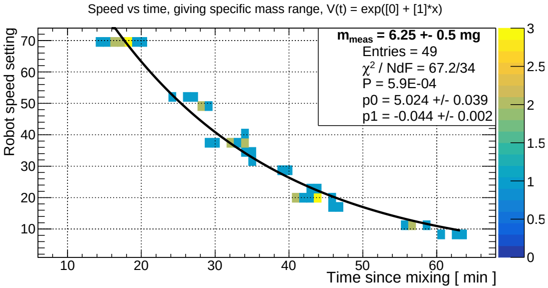

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Figure: Histograms of XY-table speed vs time since mixing - resulting in dispensing a glue mass within the given range.

$V(m, t)$ Visualisation

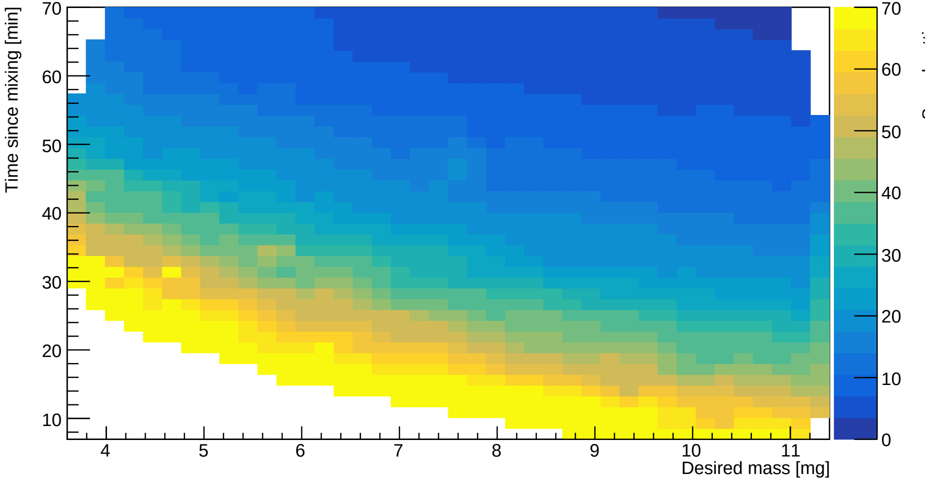


Figure: Y-axis is time elapsed since glue mixing, X-axis is the target mass and the colourbar is the XY-table speed setting accomplishing this.

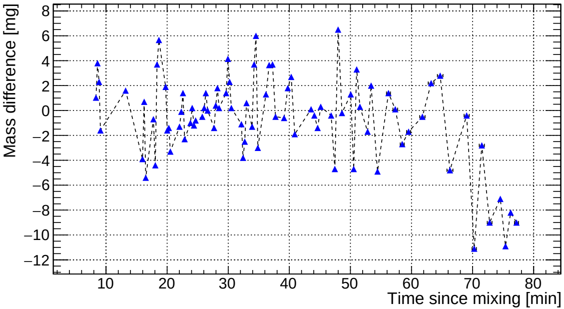
$V(m, t)$ evaluation

Performance of $V(m, t)$ was evaluated by repeatedly dispensing the RO pattern at 3 differents sets of mass settings - $m_{nominal}$ and $m_{nominal} \pm 2$ mg - - each set containing 8 different settings.

Resulting in a scanned mass range of $[15; 42]$ mg across 24 target settings.

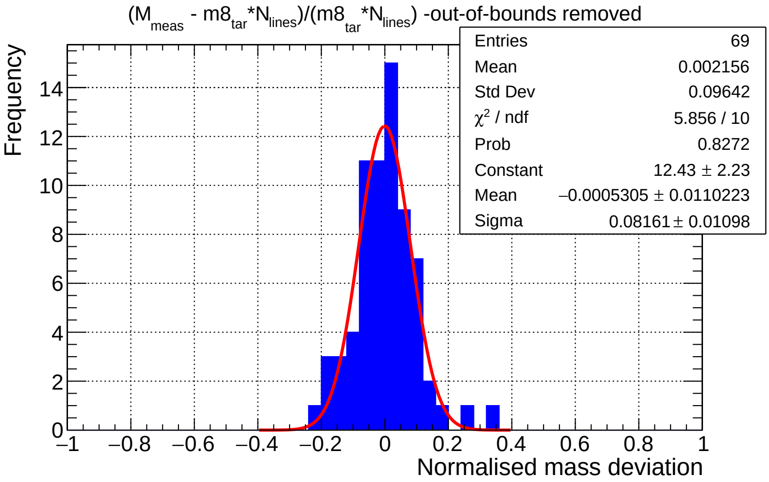
Time stability of $V(m, t)$. Not as refined as analytical approach, but, successful 3 variable calibration.

Stable until 70 min after mixing.



$V(m,t)$ evaluation

Robot precision currently at the 8 % level - while ITk baseline procedure precision sitting at ~ 10 % - operator dependent!



Glue robot - conclusion

For industry module assembly, a glue robot has been developed, using a XY-table and it's speed setting to regulate the glue flow generated by constant high pressure air flow.

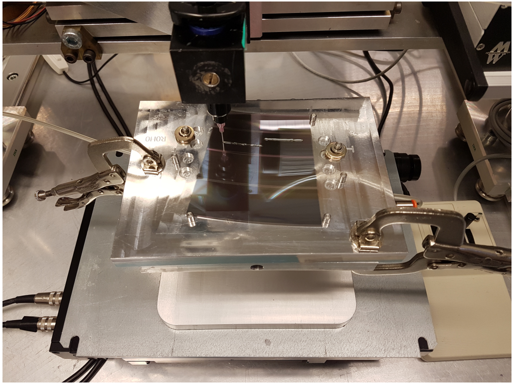
The robot has been tested capable of delivering paths containing $[15; 42]$ *mg* of glue with a precision of 8 %.

The operating window for module assembly is currently $40 - 50$ minutes, $[20; 70]$ *min* - with each module assembly taking ~ 10 *min*.

First fully functional module assembly setup in ITk - using a glue robot.

Avenues of improvement identified - setup to be optimised further before going into pre-production.

Electrical R0 production - I/II



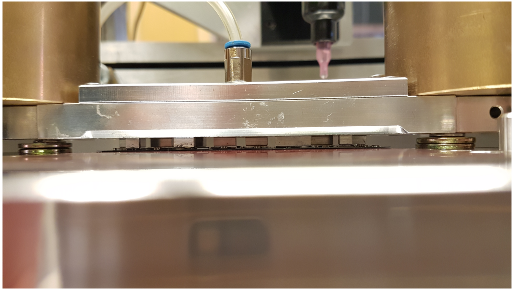


Figure: R0H0 glue pattern (*left*), R0H0 curing on spacers (*right*) and R0H1 pattern mid-dispense (*bottom*).

Electrical R0 production - II/II

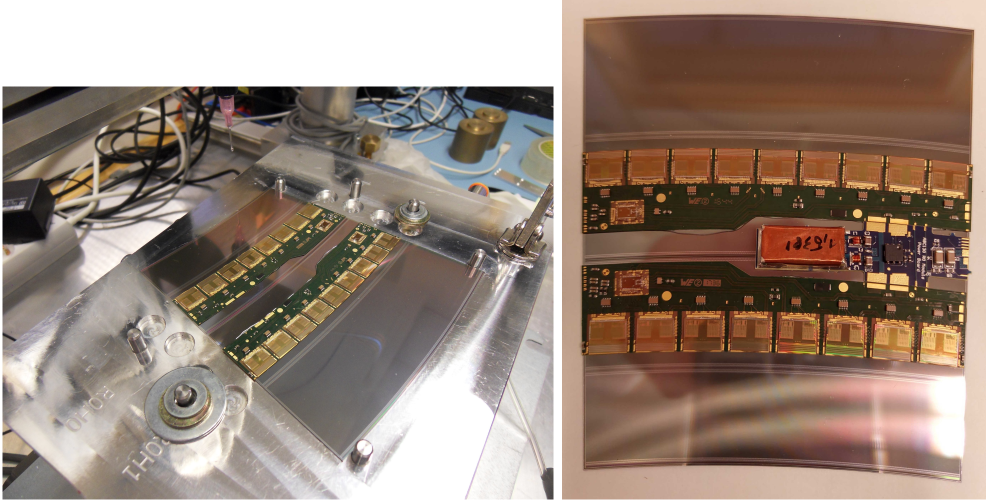


Figure: Module after gluing R0H0 and R0H1 (*left*), after full module assembly (*right*)

Summary

The Scandinavian ITk Cluster will be producing ~ 600 silicon strip detector modules for the HL-LHC upgrade of the ATLAS Inner Tracker (ITK)

Due to our collaboration with industry, alternative automated production procedures had to be developed.

This led to the succesful development of a glue robot - to be used in the attachment of hybrids and powerboards to the sensor surface.