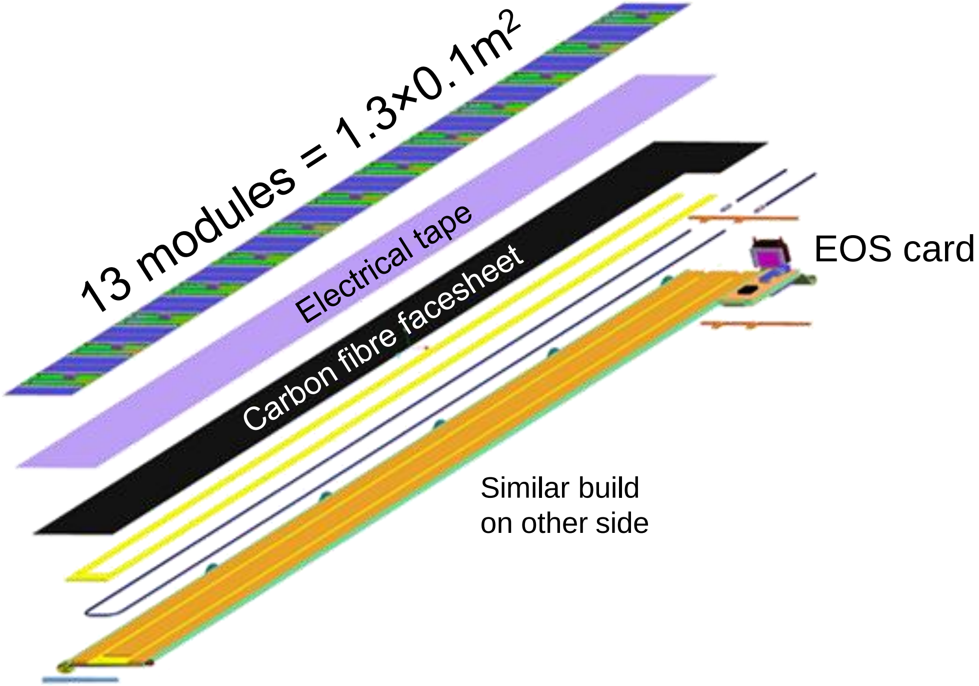
# Electrical tapes for the ATLAS phase II barrel strip tracker upgrade

Roy Wastie, Tony Weidberg
Oxford University

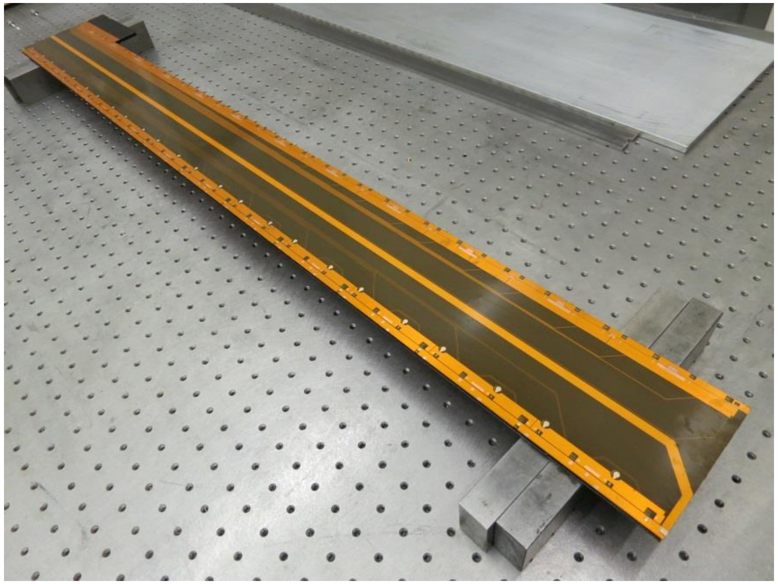
Forum on Tracking Detector Mechanics DESY

# ATLAS upgrade barrel strip stave design

- The stave is the local support in the ATLAS phase II upgrade barrel strip system
  - Mechanically: Carbon fibre/honeycomb sandwich with an embedded cooling channel
  - ~500 staves for complete barrel
- Silicon strip modules are glued to both sides of the stave
- The electrical service and data/control bus is a Cu/Kapton flex circuit (‘tape’) on top of the sandwich facesheets and underneath the modules.
  - This bus connects modules to the end-of-stave card (EoS), which contains multiplexers and the stave connector to the external services
  - All connections to the tape are done by wire-bonding




Prototype stave core with electrical tapes



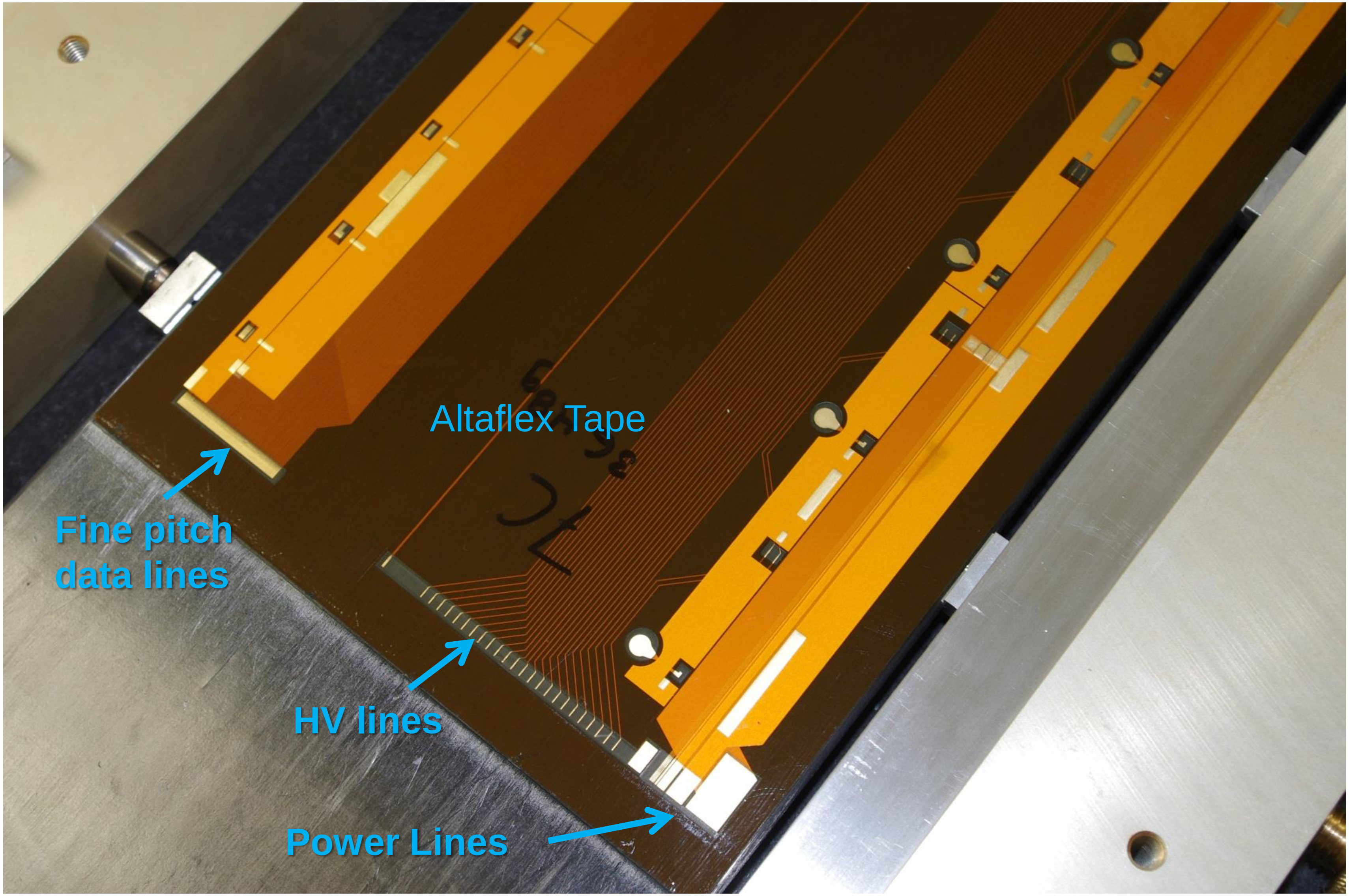
# Electrical tapes

- Supply all electrical services to modules from End of Stave (EoS) card
  - Low voltage power (for on-module DC/DC conversions or serial power)
  - High voltage for silicon (up to 500V but low current)
  - Low Voltage Differential Signalling (LVDS) data (point-to-point, 2 differential pairs/module)
  - Multi-drop LVDS (mLVDS) for trigger, timing and control (TTC) signals from EoS to modules (3 differential pairs, all modules on same bus)
  - Power control bus (4 lines, low voltage)

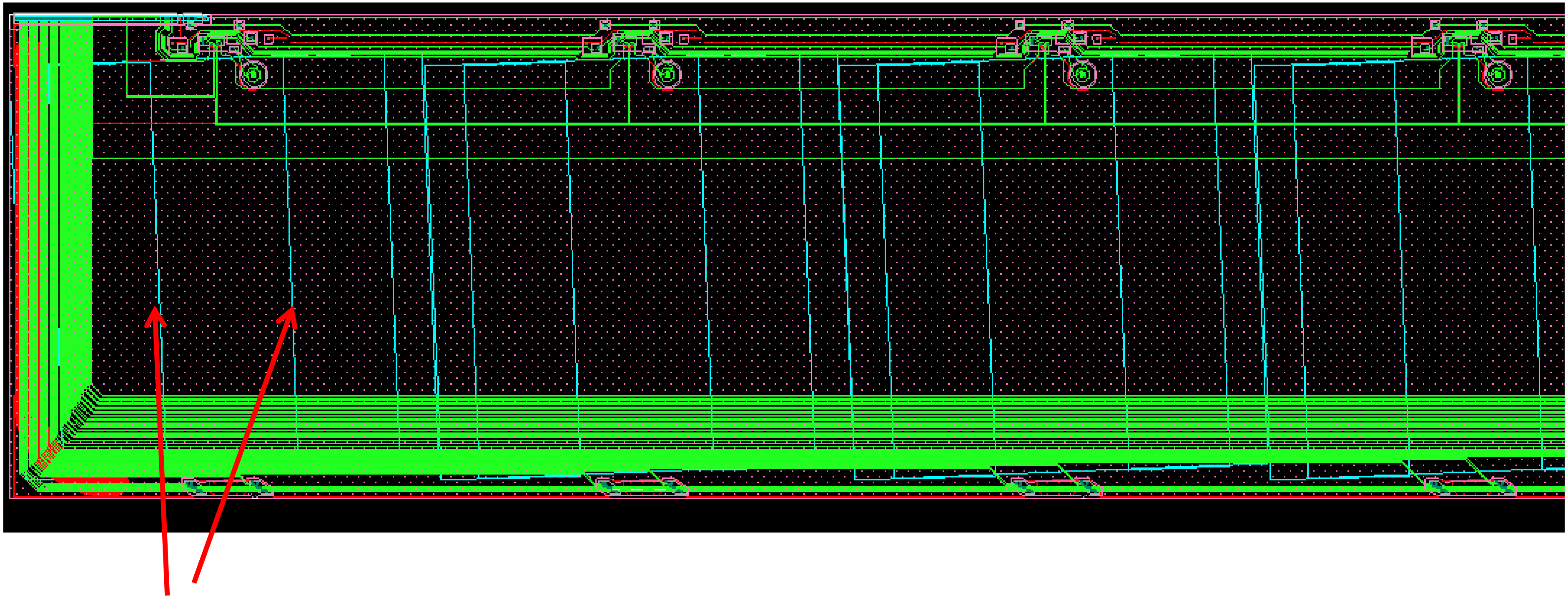
# Tape Design Rules

- For the design of the (prototype) tapes for the ATLAS strip tracker upgrade we defined a set of design rules
  - Minimum track and gap: 100µm
  - Minimum bond-pad width: 150µm
  - Separation between HV and LV lines/pads: 0.8mm if under Kapton and 1.75mm if not under Kapton
    - This is a spec from UL (industrial standard)
  - Gaps between pads and cut-outs on cover layer: >1mm
- This is a set of design rules which we chose because we are confident that large scale tapes can be produced following these rules with a large success rate

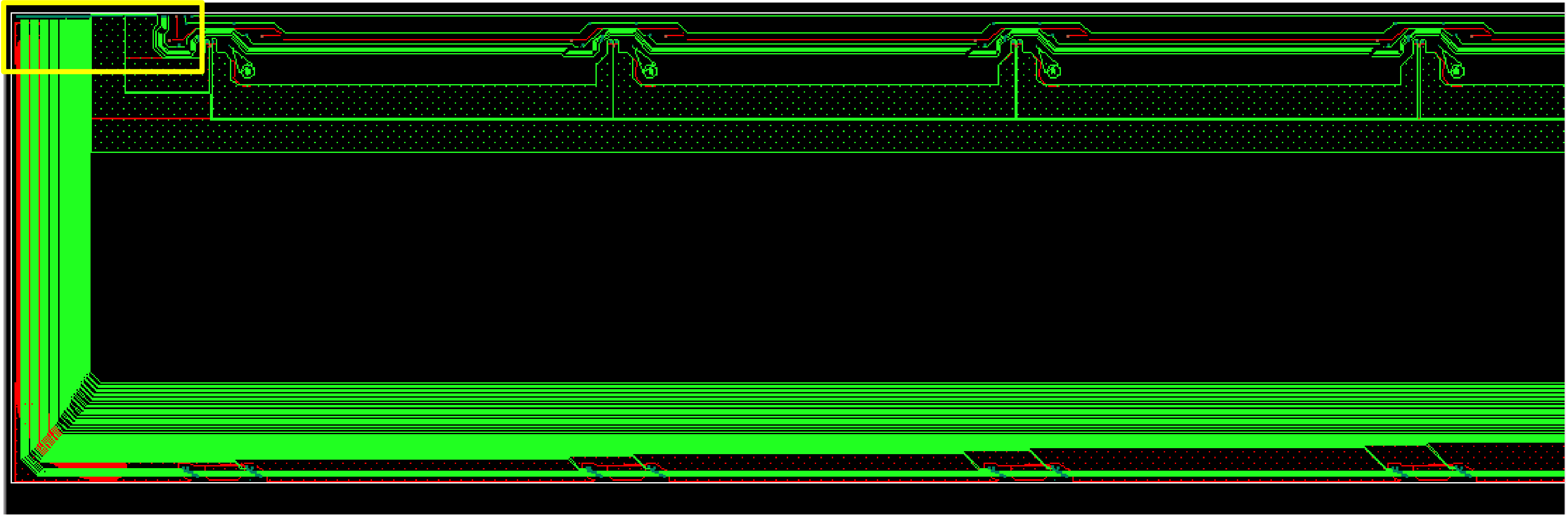
# Trace geometries



# Tape Layout

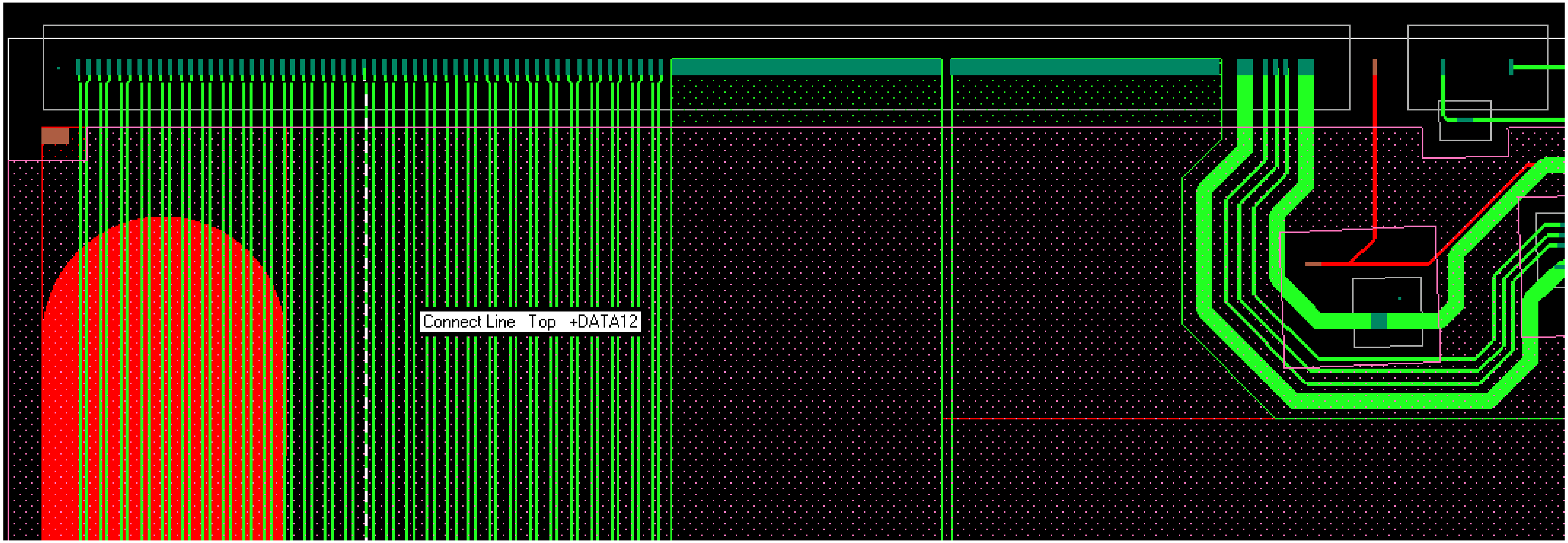


# Tape Layout

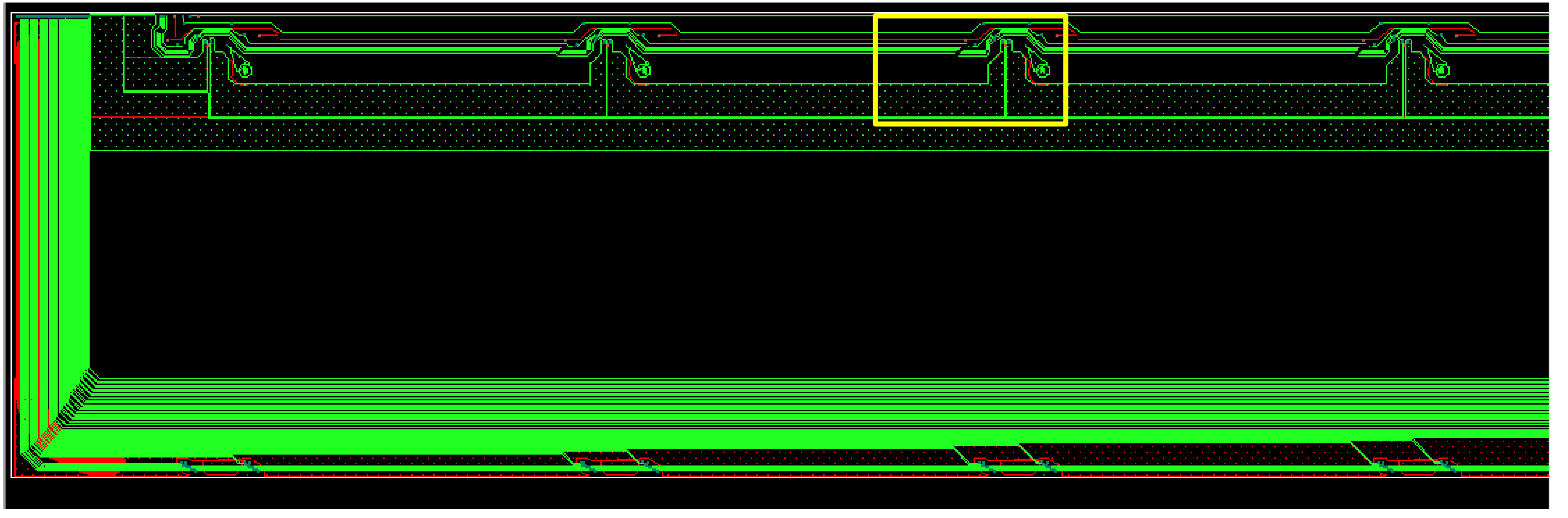


# Tape Layout EOS

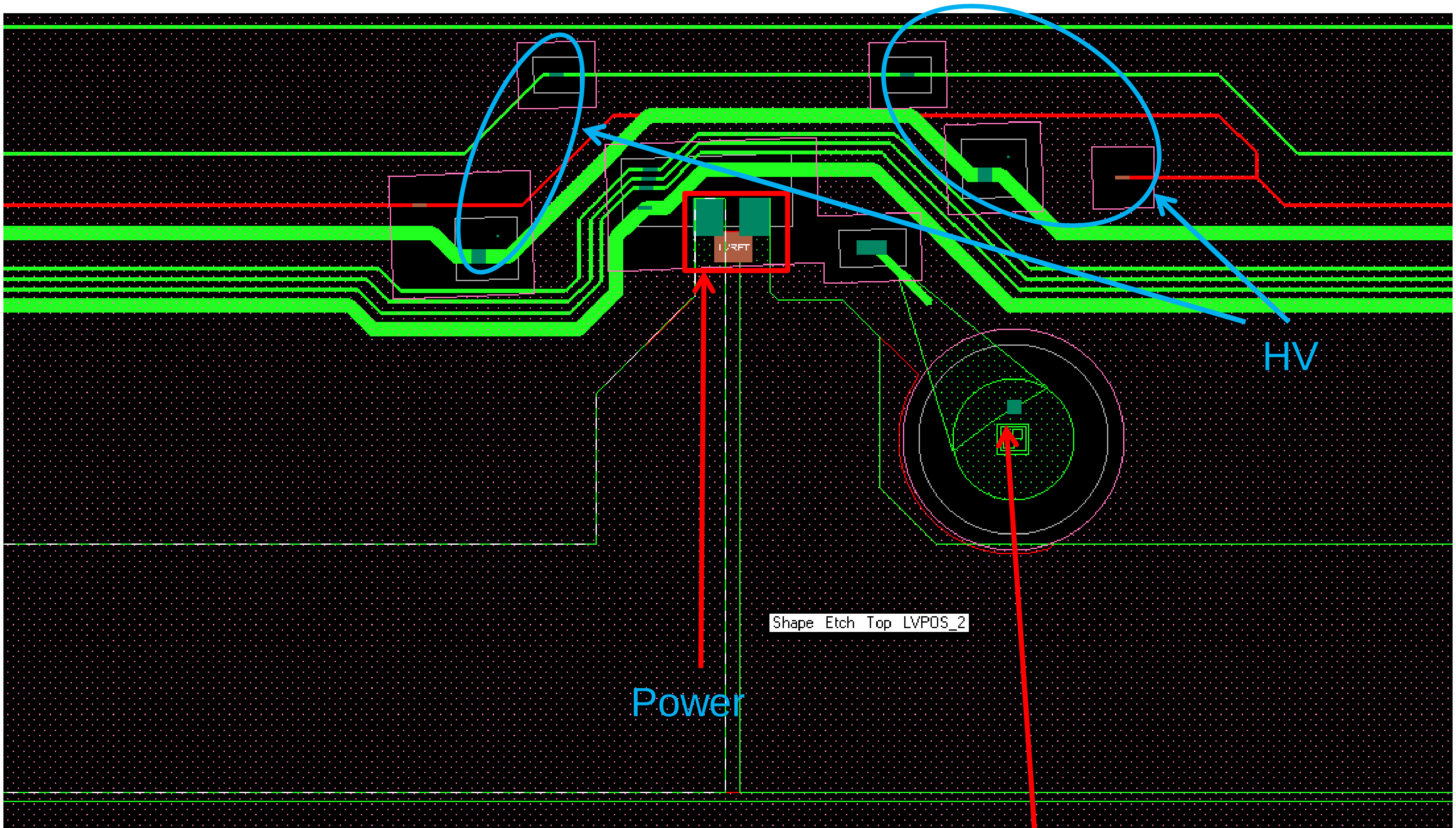
Data TTC LV Power Control HV



# Tape Layout

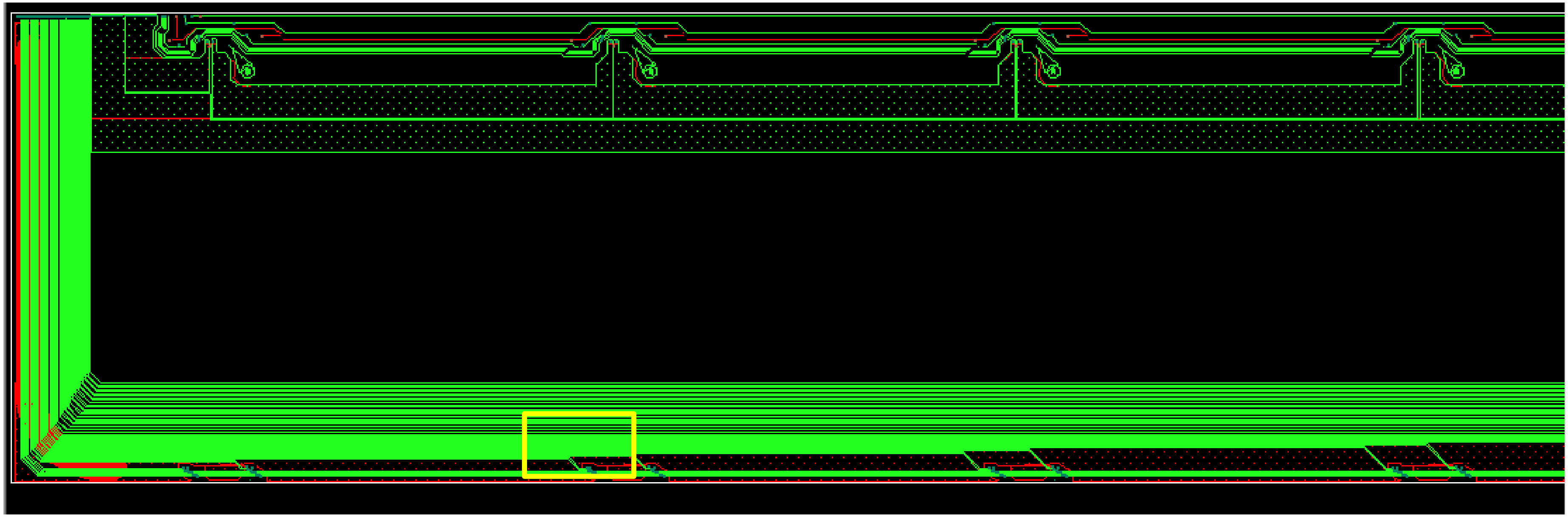


# Tape Layout HV Power

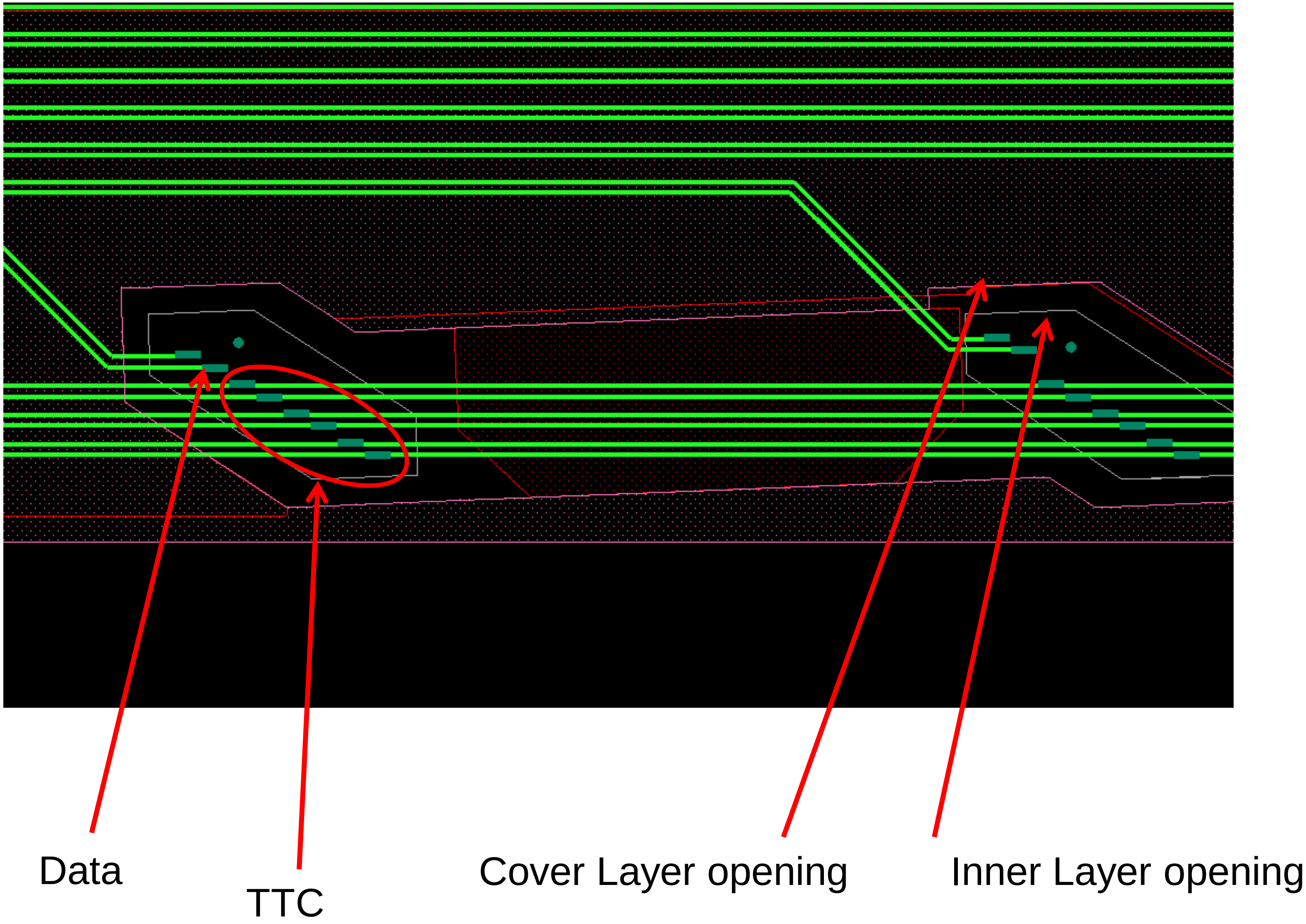



HV Backplane connection

# Tape Layout



# Tape Layout TTC Data



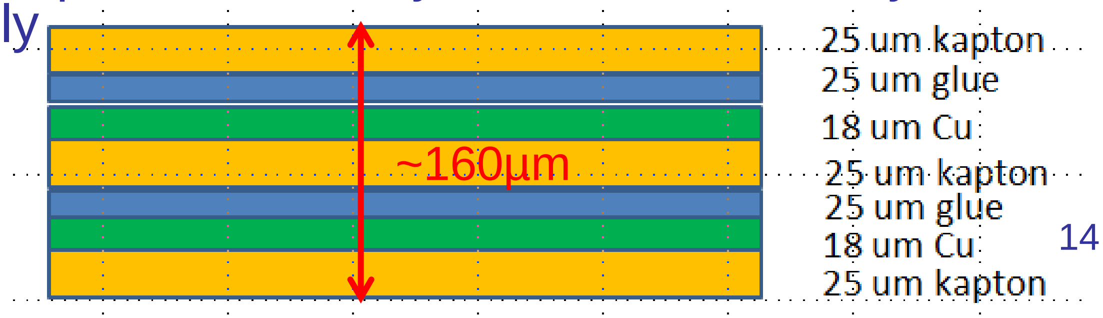
# Tape material

- Use Cu/polyimide (Kapton is DuPont trademark for one version of polyimide)
- Best reliability is achieved by
  - Cast material as opposed to glued (polyimide flowed over copper)
  - Copper is rolled annealed
  - No glue to fail with radiation
- Alternative adhesiveless material is electro-deposited material (Cu layer grown electrolytically on seed layer)
  - Easier to maintain flatness after etching.
- Typically 25µm polyimide (other options are 12µm and 50µm)
- Different copper thicknesses possible
  - We used 18µm (other common options are 9, 12 or 35µm)

# Tape build

- Can do multiple layers but vias would be very challenging → avoid if possible
- Connection by aluminium wire-bonding
  - Use electro-less Ni/Au plating of bond pads (CERN-approved recipe for reliable wire-bonding)
- We have used two electrical layers + cover layer
- In principle one can use Al instead of Cu
  - Attractive in principle because $\sigma \times X_0$ better by factor 3.7 than for copper …
  - But the process is vastly more difficult
    - has been done successfully by Rui de Oliveira @ CERN Photolab for ALICE
    - If not done properly there is a high risk of chemical damage resulting in cracks in the traces
  - Our advice: avoid Al if possible and if you need it, think of your process very carefully

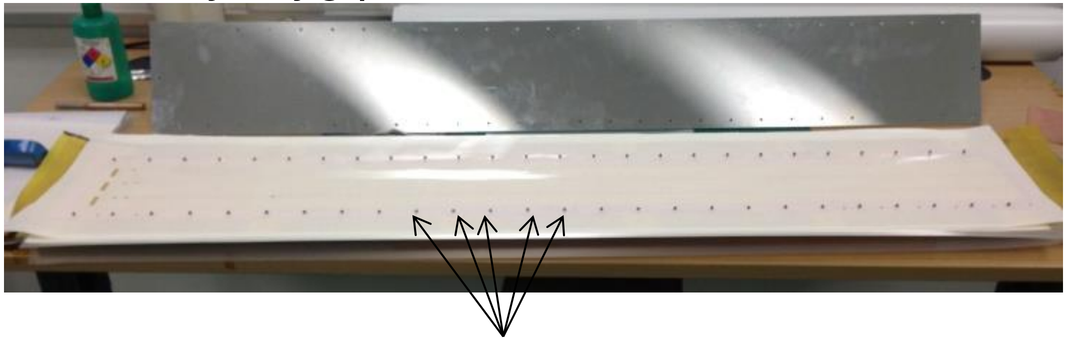
Use Dupont LF materials

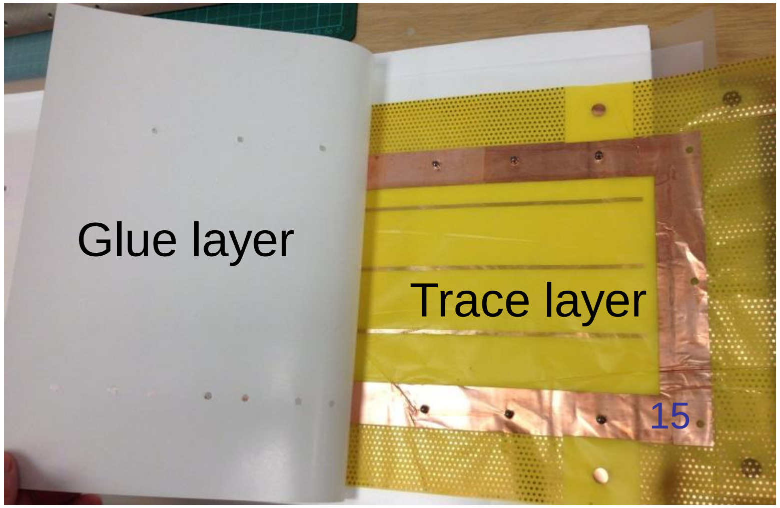


# Tape manufacture

- Handling
  - Process cleanliness: Wear Gloves, clean room clothes. All work in semi clean/cleanroom
- Alignment is maintained between layers using dowel holes and a jig plate. The holes are cut using a CNC knife cutter and alignment fiducials on the artwork
- Process steps:
  1. Laminate photo resist to Cu/Kapton
  2. Images tape with artwork
  3. Strip photoresist
  4. Check photoresist
  5. Etch Cu layers
  6. Strip photoresist
  7. Surface preparation to Cu layers
  8. Bake out of Cu layers
  9. Cut alignment holes and access holes in Cu layers
  10. Cut glue/cover layer
  11. Cut press materials conformance packing, release film etc.
  12. Load jig plate
  13. Laminate tape in hydraulic press 20kg/cm$^2$ for 30mins @ 185°C

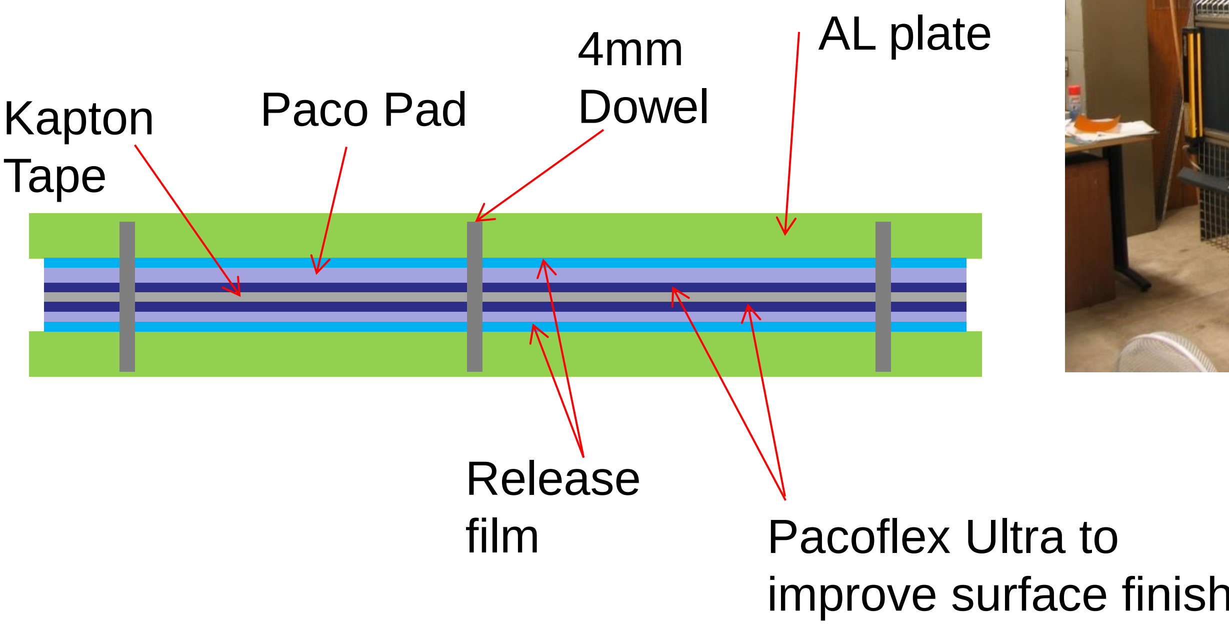
Assembly in jig plate



# Lamination

When pressing load jig into cold press apply pressure 20kg/cm$^2$ and then turn on heat 185°C for 30mins ramp up 30mins hold then Cool down 8hrs under pressure.

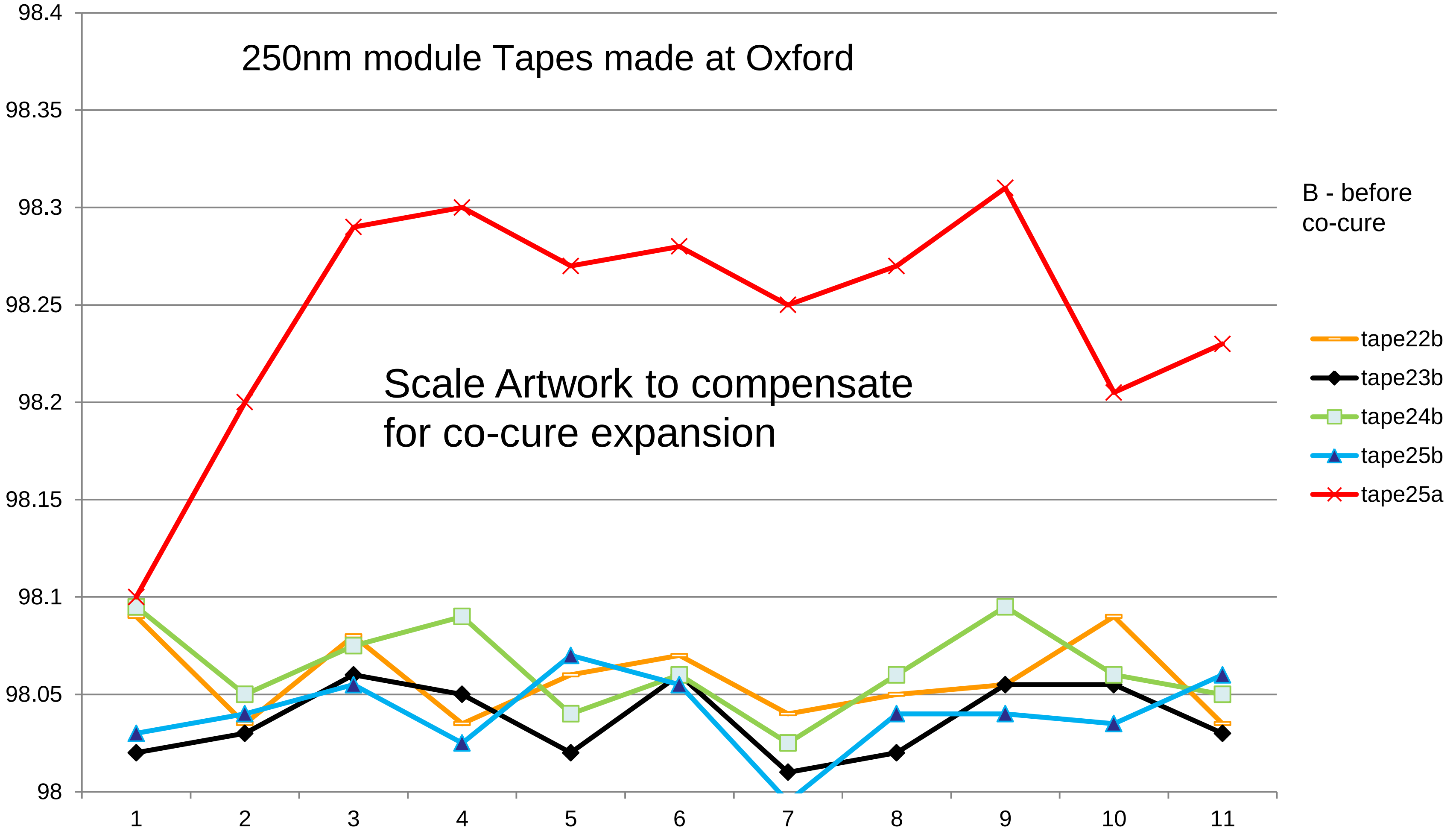




Press

Dowels 4mm close to tape edge and spacing between depends on accuracy required in alignment, up to every 5cm

# Tape length Measurements

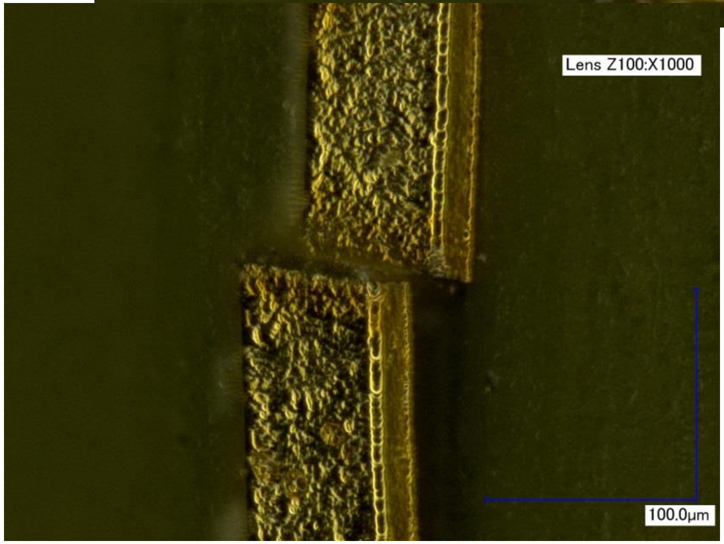


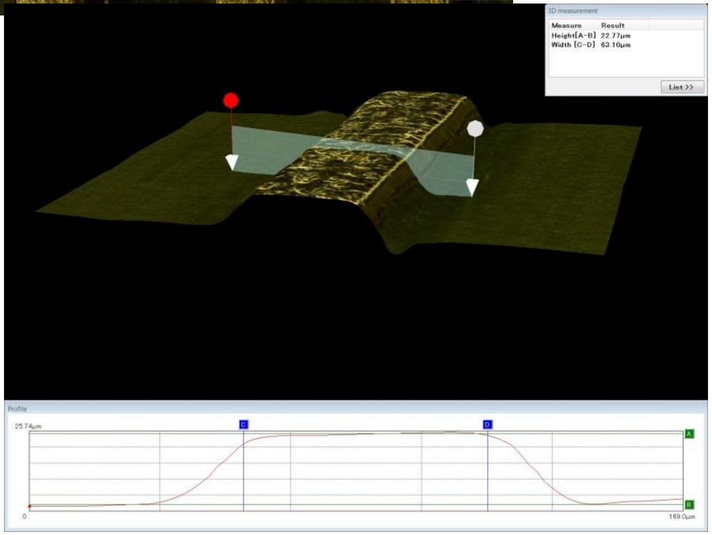
# Tape manufacture lessons learned

- Surface preparation
  - It is very important to keep all materials free of dirt, grease and moisture
  - To get good adhesion when laminating we abrade lightly the surfaces of the Cu kapton layers with pumice and water using a brush
- Alignment
  - A variety of fiducials needed to be included into the tape design as they were needed for manufacture and subsequent tape testing
    - Dowel holes and fiducials used during tape manufacture
    - Other fiducials have been added for measuring the physical dimensions of the tape and providing alignment for tape testing, stave core build and wire bonding
- Immersion nickel/gold plating
  - Adhesiveless Copper/polyimide material is sensitive to the plating solutions. If it is excessively alkaline it will cause delamination of the copper tracks. We found we had to change to use the PCB facility at CERN.

# Immersion nickel/gold plating defects



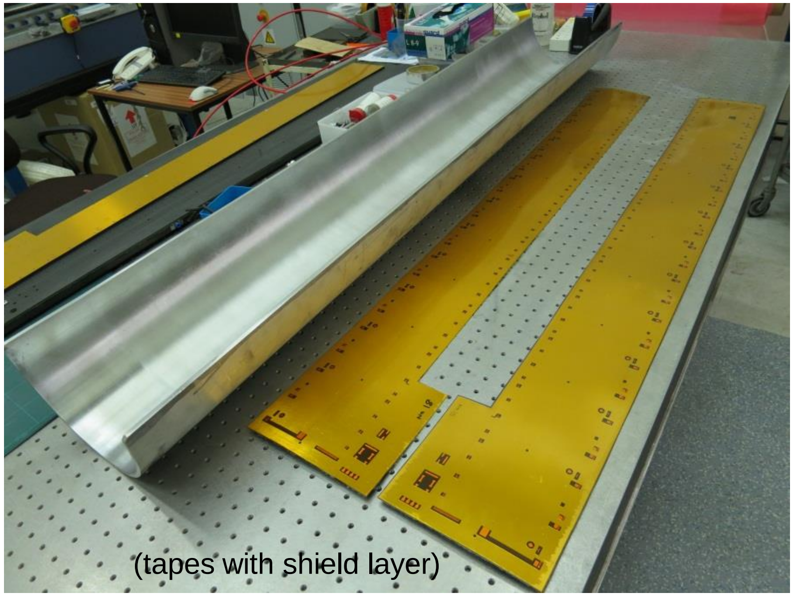


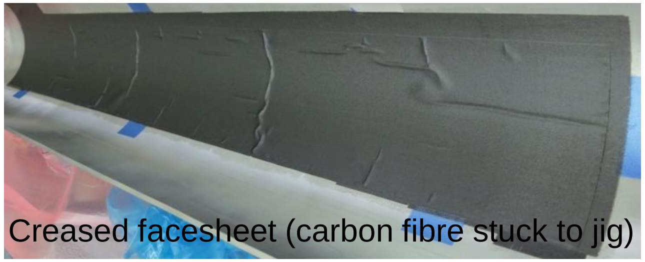
# Co-curing

- To save glue and avoid the challenging gluing of large flat objects we do co-cure the tape with the carbon fibre facesheets
  - 3 layers (0/90/0) of K13C2U(45gsm)/EX1515
  - Cure at 120°C
- Originally suggested by Oxford, tooling perfected by Berkeley
  - To compensate for differential thermal expansion of tape and carbon fibre cure in an Ø10” Al half-pipe in the autoclave
- Lessons learned
  - Prepreg needs to contain sufficient resin (otherwise delaminations within the facesheet)
  - Facesheet must be free to expand/contract on the jig (otherwise facesheet creases)
    - No excess carbon fibre around the electrical tape
    - No sticking down of facesheet
    - Release autoclave pressure before cool-down
  - Resin bleed onto tape surface can be avoided by adding a 10mm sacrificial rim around the tape
    - This rim is kept during stave build to prevent glue bleed in subsequent assembly steps and is milled away at the end of the sandwich production

Half-pipe jig



(tapes with shield layer)

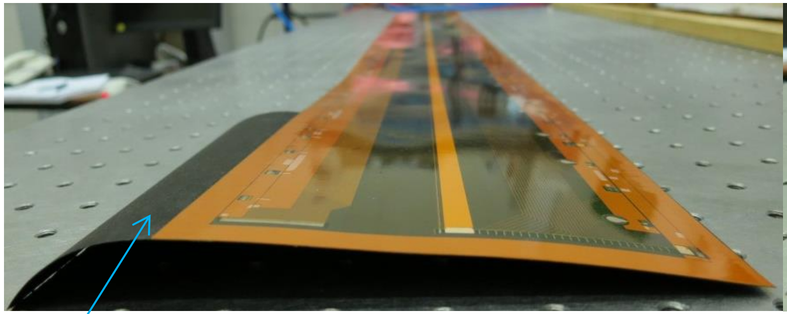


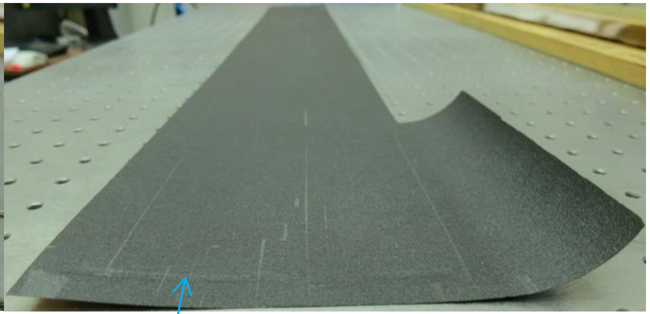
Creased facesheet (carbon fibre stuck to jig)

Resin bleed

Sacrificial rim

# Co-curing details

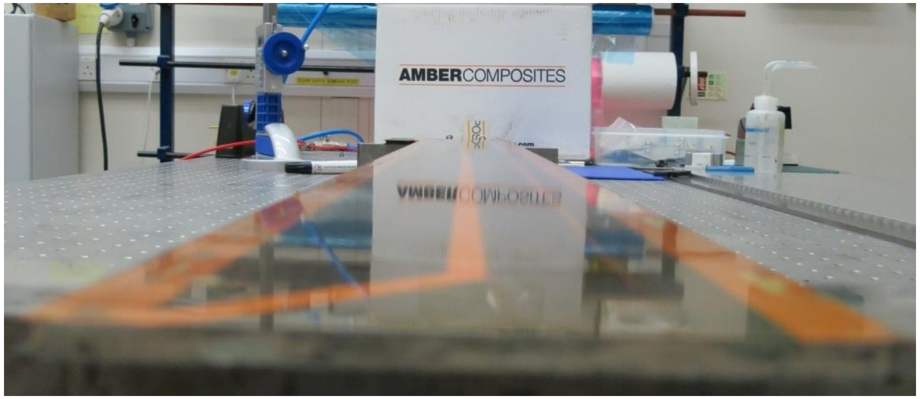




EOS area has no tape
→ retains curvature of jig
Easily flattened during sandwich production

Slight dimpling on backside due to reduced tape thickness in cut-outs
Filled with glue during sandwich production

Co-cured CF/tape facesheet after assembly into stave sandwich
Note mirror-like surface finish (global flatness ±100µm)

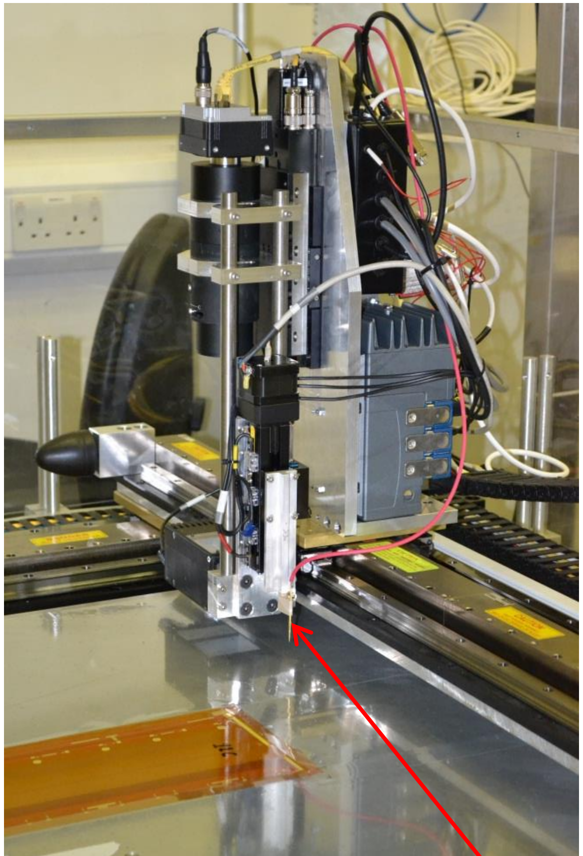


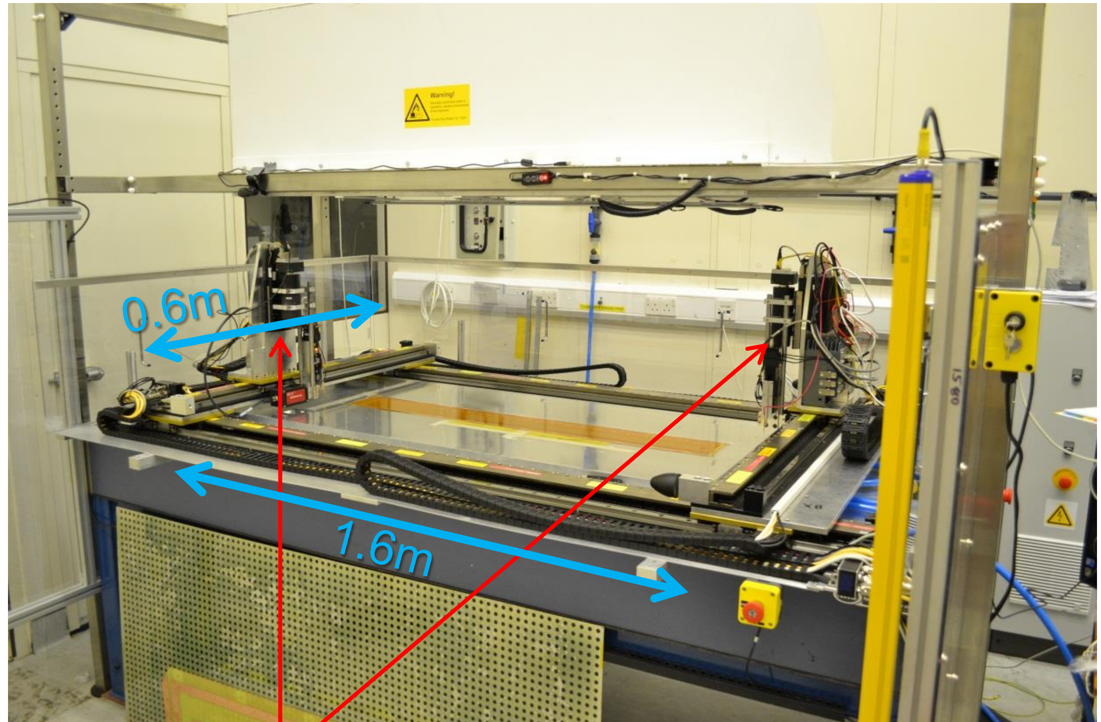
# QA during tape production

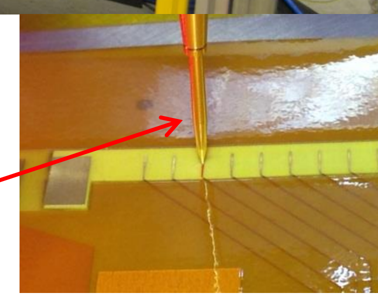
- Optical inspection of pads
  - Check uniformity and quality of the surface and dimensions
- Mechanical QA
  - Check locations of bond pads to make sure that modules can be placed and wire-bonded correctly
- Electrical QA
  - Measure resistance between all pads on the same net
  - Check insulation between neighbouring lines
  - HVIR (High Voltage Insulation Resistance) between HV lines
    - Apply 500V to HV line and measure leakage current. Spec > 1GΩ.
  - Many 100s of measurements per tape
- Need to repeat these measurements at different stages of stave core assembly

→ Automation essential. We have build a robotic system for this
  - 2 independent probe heads with cameras for alignment
  - xyz position control by linear stages (Range x 1.6m, y 0.6m) with 5μm resolution
  - Spring loaded gold probe as used for industrial PCB probing
- This system is designed to automatically test a tape in less than 1h

# Tape testing robot





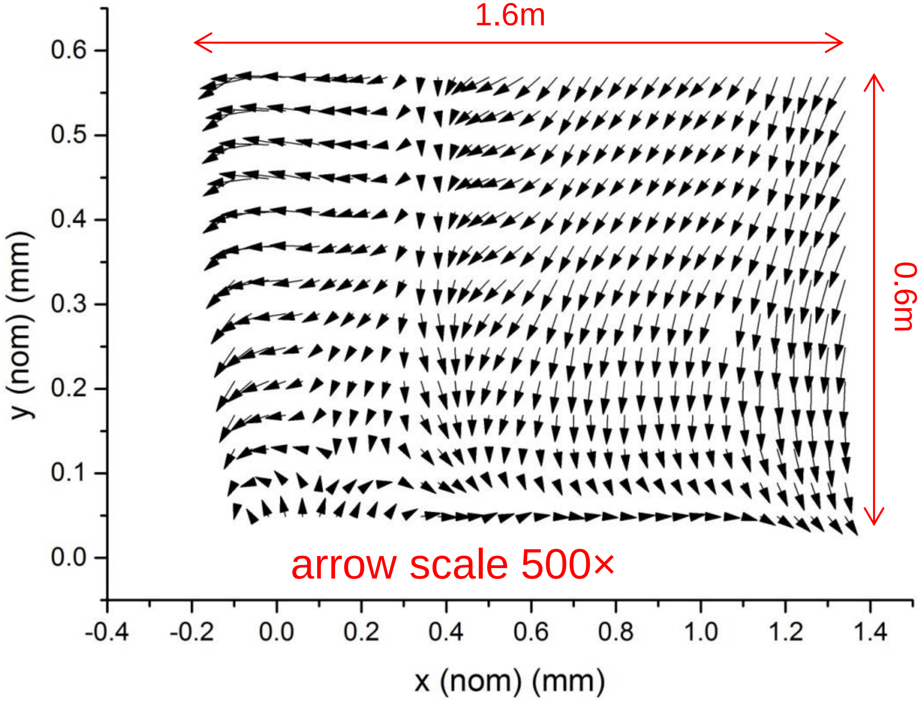
2 independent probe heads with cameras for alignment with XYZ control

Probes

# Calibration of stage positions

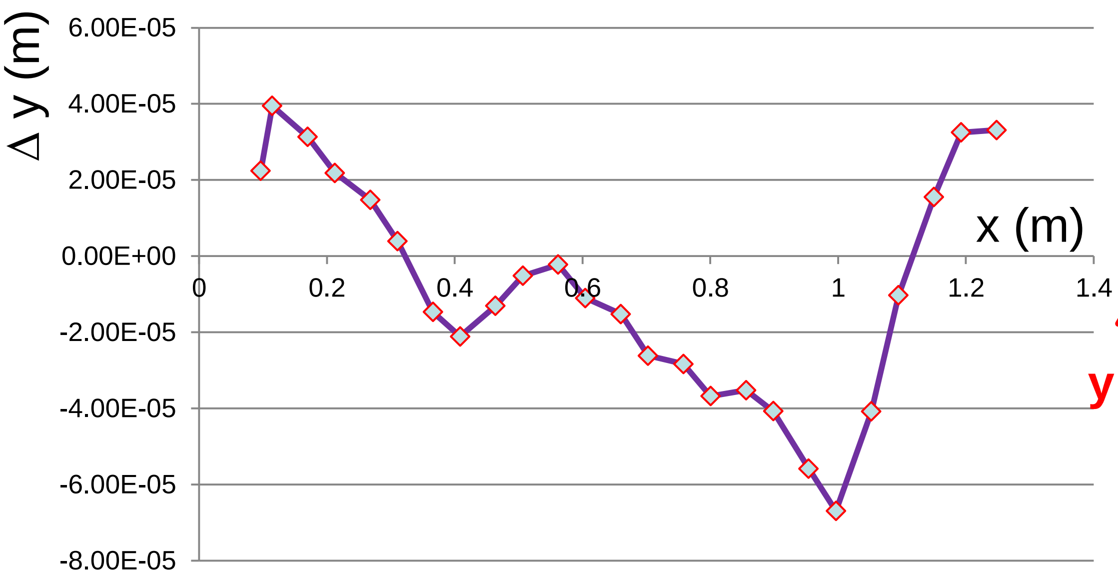
- Use a calibration plate with 2cm×2cm grid of black dots in regular pattern covering the full travel area of the robot
  - Actual positions of dots were calibrated with a Smartscope
- This calibration plate was then surveyed by the tape testing robot
  - Produces a look-up table of robot coordinates vs real coordinates
  - Intermediate positions from linear interpolation
  - Good reproducibility (3-5μm RMS)
  - Offsets between robot position and real coordinates up to ~200μm
- These offsets are larger than the size of the bond-pads, so calibration is necessary
- Similar results for both stages

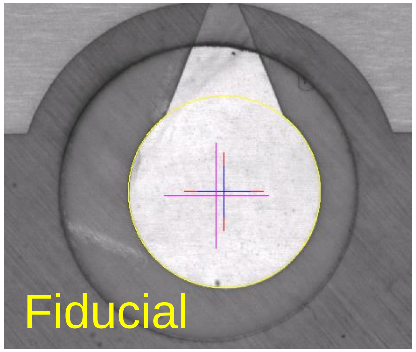
Stage1 stage displacements

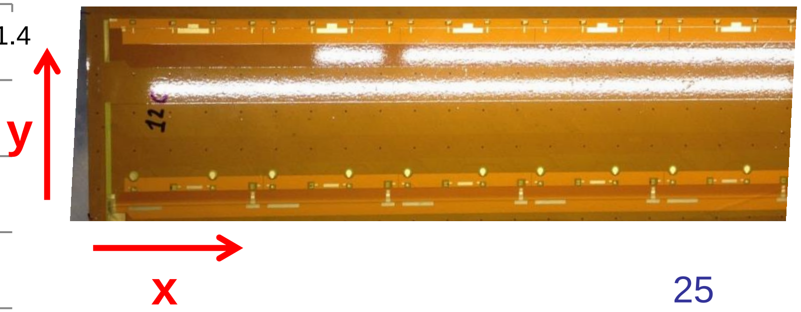


# Tape dimensional accuracy

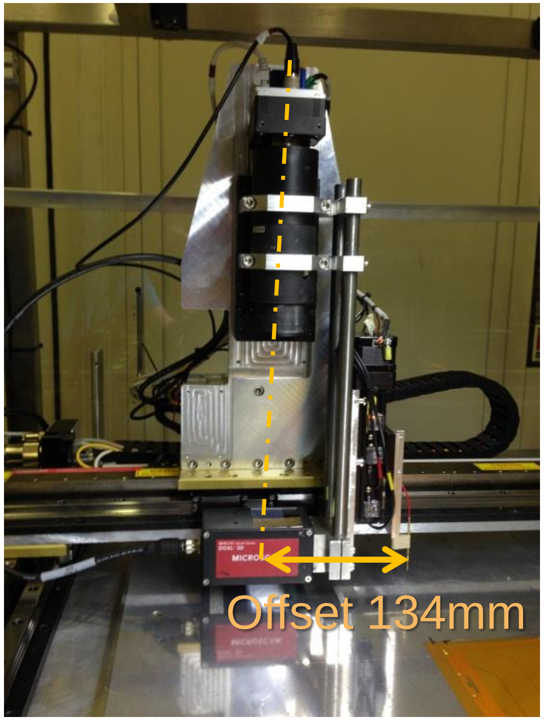
- After robot calibration we measured the position of features on the tape surface
  - We found large deformations within the tape (order of 100µm)
  - These are probably caused by the flexibility of the Kapton material during the lamination process
    - We have also measure tapes made of FR4, distortions are much smaller there
  - Range of offsets too large for probing (displacements are similar in size to the bond pads → probing would become impossible)
- Distortions are genuine (confirmed with Smartscope)
- Need to position the robot heads using local fiducials



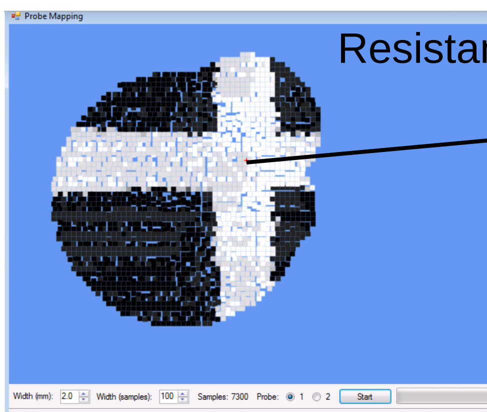



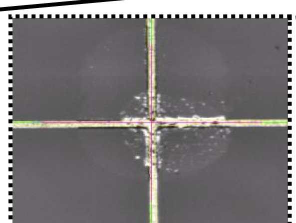



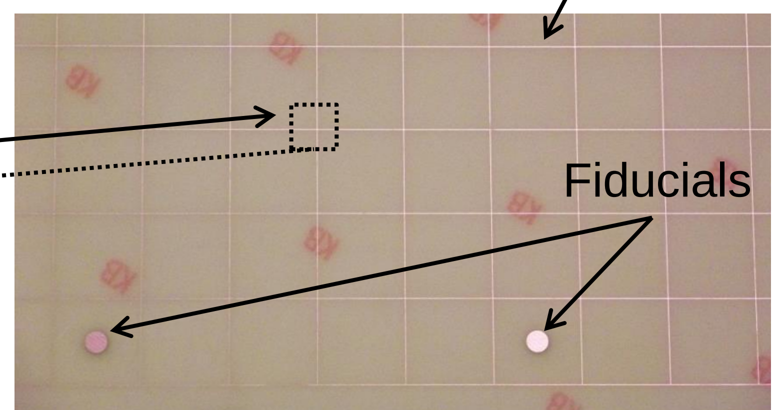
# Camera-to-probe calibration




- An additional calibration required is to calibrate the offset of the probe position from the camera
- This was done using a PCB with a grid of traces and fiducials
  - Find fiducials with the camera
  - Scan probe over grid and measure resistance to find the grid lines
- Generate a lookup table and find offset by linear interpolation

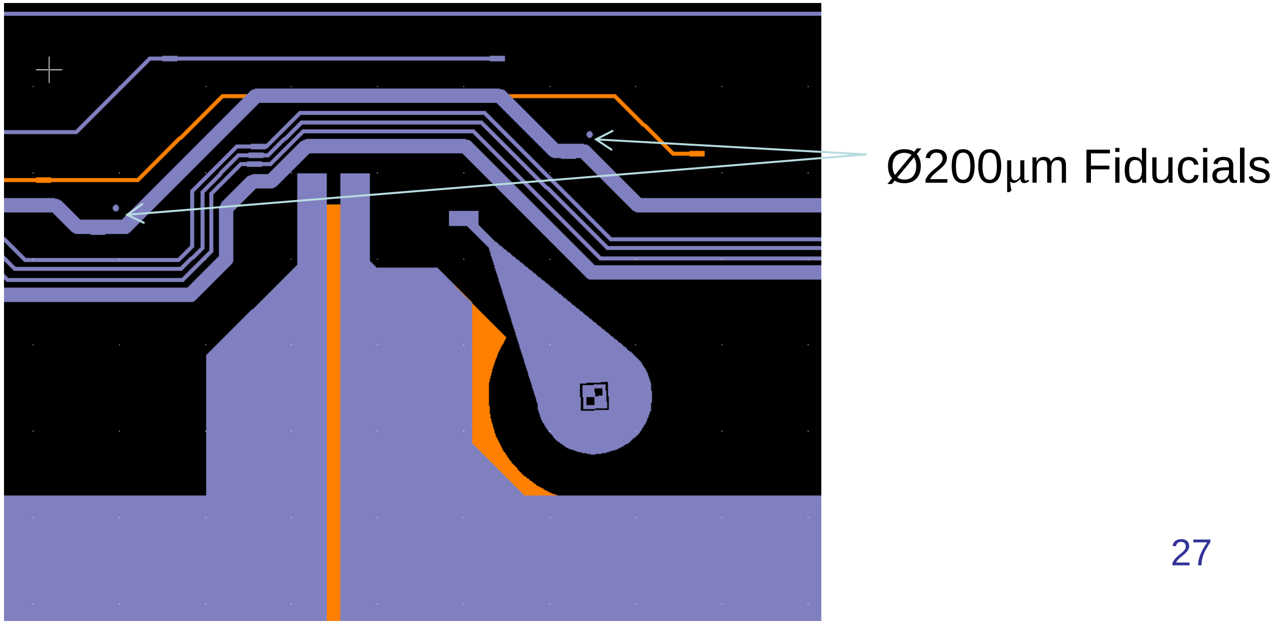




# Test procedure

1. Find tape position using robot cameras surveying global tape fiducials
2. Position probe heads on tape
   - Map nominal pads locations (from CAD file) to stage coordinates
   - Additional correction using local fiducials to allow for tape distortions
   - Include camera-probe offset
3. Perform electrical tests
   - Open circuit and short circuit tests
   - HV insulation resistance testing >1GΩ
4. Repeat from 2.



# Outlook for production

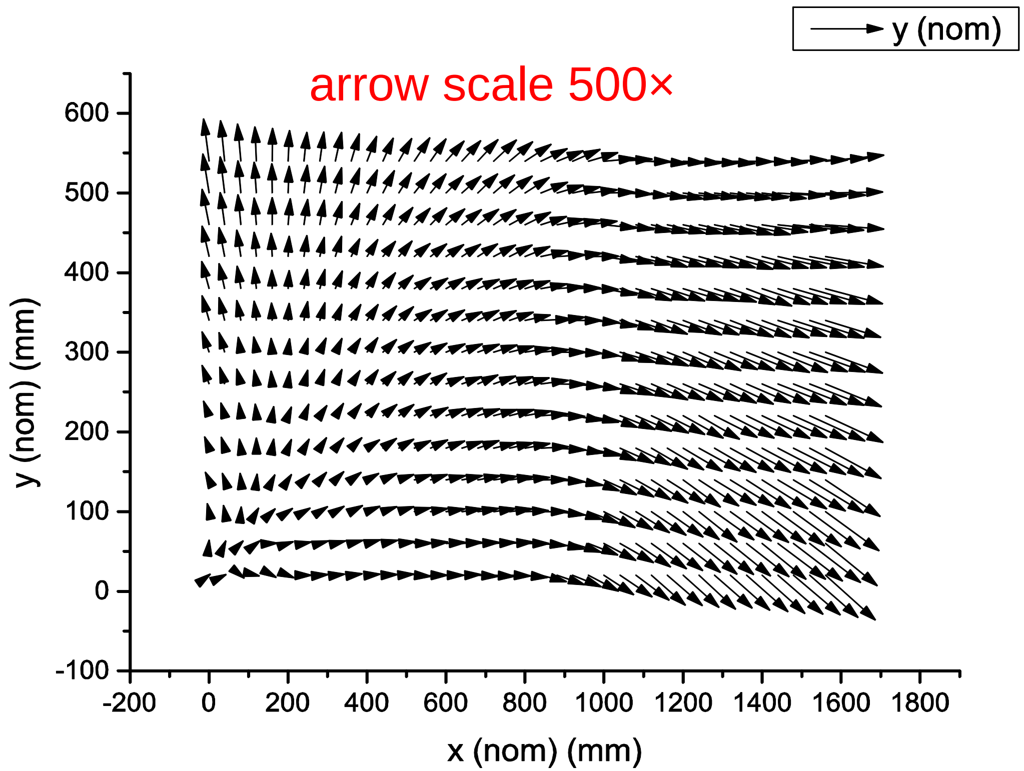
- For the complete phase II strip barrel ~500 tapes will be needed
  - These will most likely be produced in industry
- As part of the distributed stave core production QA and co-curing will be done at several sites
  - Several copies of tape testing robot needed

# Conclusions

- We have designed and manufactured large tapes (1.3m long × 10cm wide) Cu/polyimide multi-layer tapes with fine pitch features
  - 100μm track & gap
  - Tape size only limited by tooling (exposure units, developing systems, laminate press)
- We have developed an automatic testing system for the QA of these tapes
  - This is required for the final ATLAS stave manufacture (~500 stave cores) and by the large number of networks on each tape
- Tapes are dimensionally not very accurate (~100μm)
  - Cannot rely on accurate position of bond pads for testing and subsequent stave assembly
- Co-curing of full-size tapes is now working reproducibly
  - In principle size limited only by size of autoclave
  - Shape can be moulded (here: flat, but other geometries seem possible)

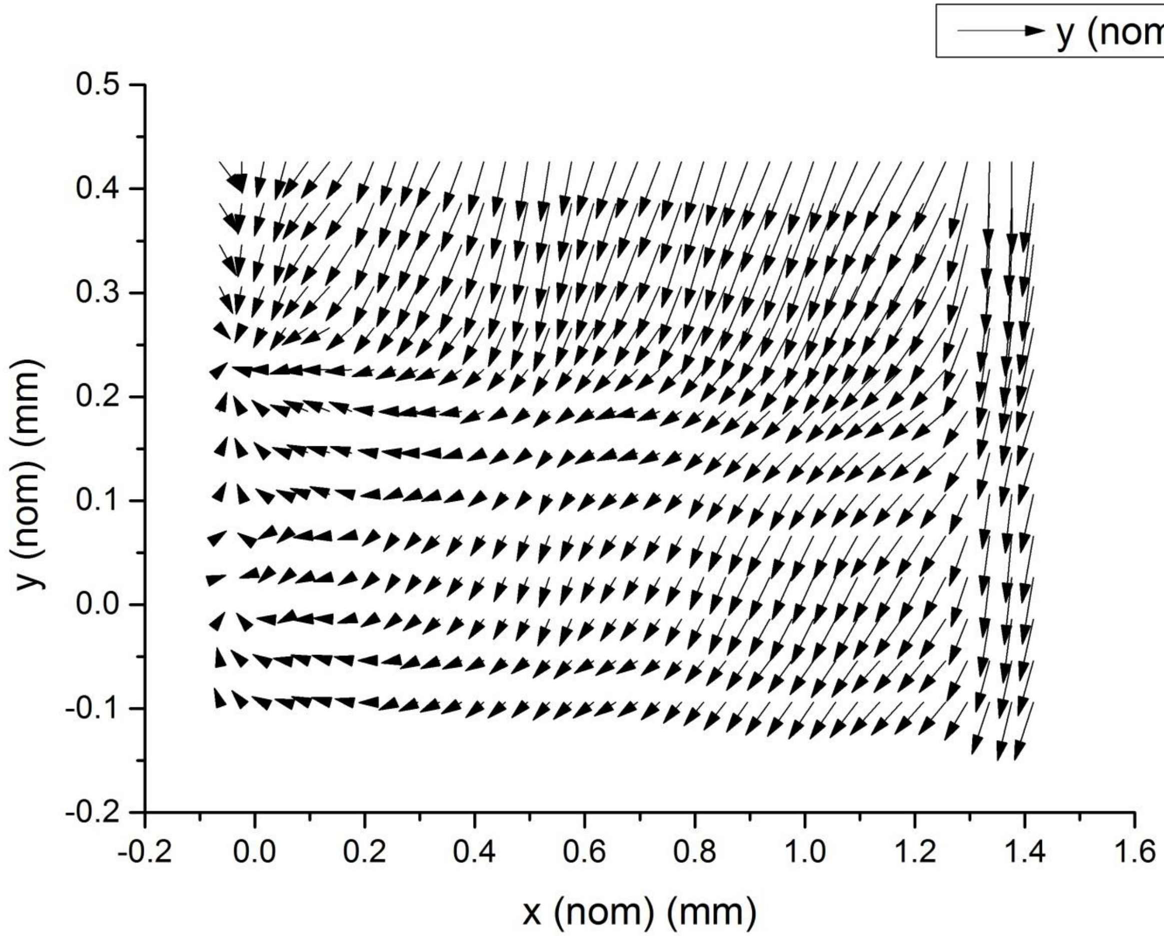
# Backup slides

# Calibration plate survey




- Difference between Smartscope calibration and robot position measurement

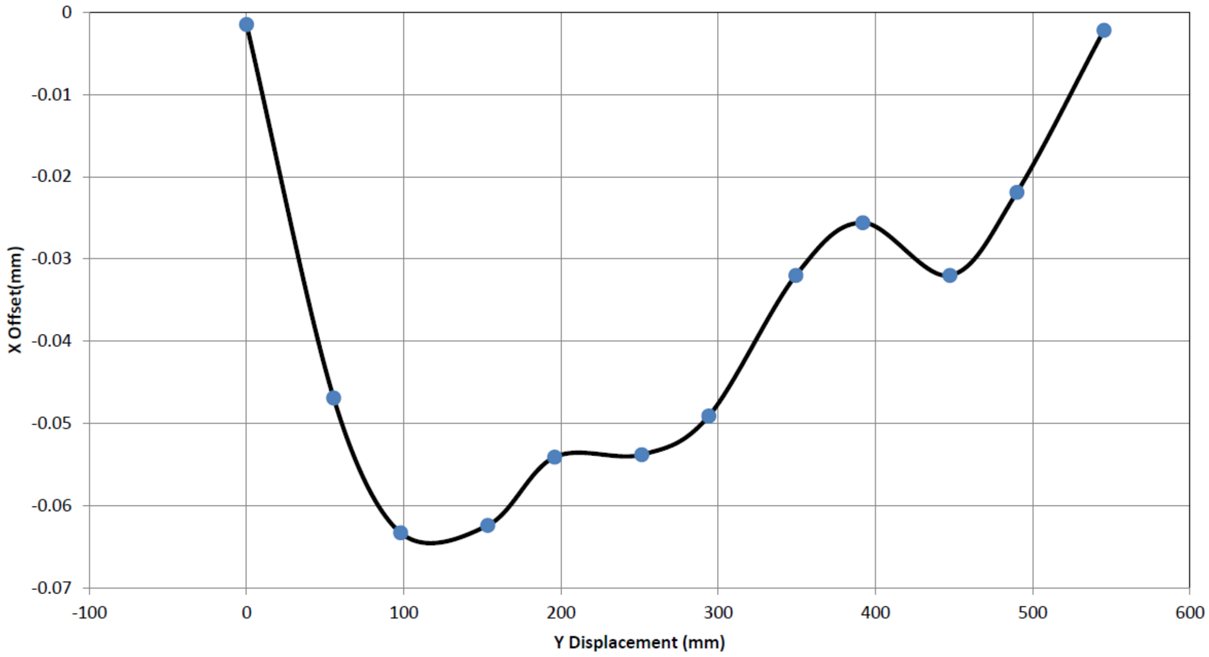
# Stage 2 Calibration




**Arrow: true to measured location**
**Scale = 500**

# Smartscope measurements of tapes

- Measurements using Smartscope from part of another tape from same batch
- Measured HV pads also show large offsets



# Measurements on FR4 Tape

**Offsets very much smaller ➔ distortions of kapton tape are real**