Design, Production and Testing of ATLAS ITk Strip Bus Tapes

Tony Weidberg for ATLAS ITk strips

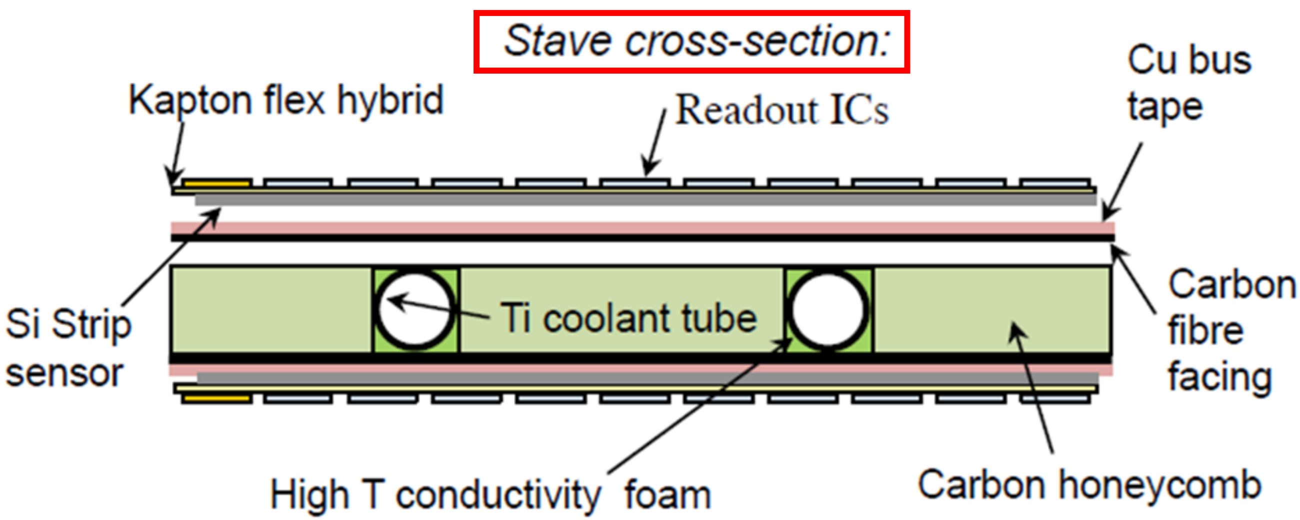
DESY, LBL, Ljubljana, Oxford, Valencia, Yale

Outline

- Introduction
  - Staves and petals
- Bus tape requirements
- Challenges and technologies
- Bus Tape Testing Robots (BTTR) for QC
- Electrical results and data transmission
- Dimension measurements
- Radiation tolerance
- Summary

ATLAS Staves & Petals

- Silicon strip modules mounted on cores
  - Provide all electrical (LV, HV & data) and cooling services (CO_2)
  - Integrated ➔ minimum radiation length.
  - Same concept staves (barrel) and petals (End cap) different shapes



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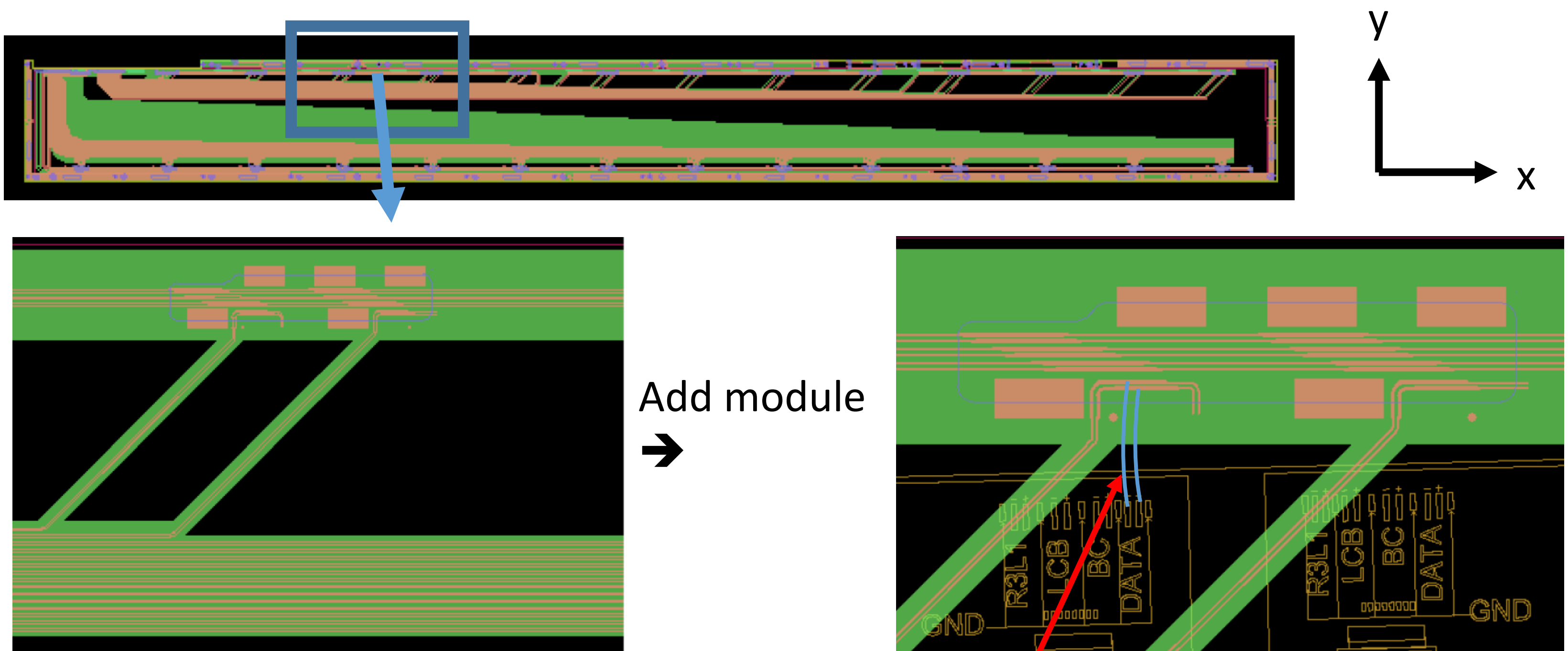
Bus Tape Requirements

- Electrical
  - 640 Mbps data from modules to End of Stave (EoS) card
  - 160 Mbps control data EoS ➔ modules (multi-drop)
  - Impedance $Z_0 = 100 \pm 10\ \Omega$
  - LV (11V) to modules
  - HV (up to -550V) to modules
- Mechanical
  - Minimal radiation length
  - Silicon modules mounted on stave: bond pads need to match up ➔ spec on stretch/shrinkage
  - HV clearances ➔ spec on distortions.
- Radiation tolerance
  - Barrel: 500 kGy(Si) : End Cap: 650 kGy(Si).
  - Check adhesion of glue for cover layer to tape.

Geometrical Constraints

- Bare stave tape (1.4 m long)



- Modules wire bonded to bond pads on tape
- Module located precisely wrt stave ➔ constraint on tape stretch
- HV clearances would be compromised by large distortions in y direction.

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Challenges

- Long tapes (barrel) with 100 μm track & gap up to 1.4 m long (barrel).
  - Precise etching. Control impedance Z_0 = 100 Ω.
  - Getting high yield
    - Up to 44 narrow (~ 100 μm) tracks on tape. One open circuit ➔ tape fails.
  - Uniformity of NiAu plating
  - Uniformity of Cu thickness for electro-plating.
- Difficulty finding commercial manufacturers for long barrel tapes
  - Company that made prototypes withdrew for commercial reasons
  - Second company making progress but tapes failed radiation tests.
  - Development and production at CERN (Rui's workshop).
- Petal tapes produced at Elgoline
  - Tapes not as long as barrel tapes. Company couldn't make 1.4 m long tapes for barrel.

Tape Technologies

- Two Cu layers on adhesiveless polyimide.
- Polyimide + glue cover layer top and bottom.
- Two technologies

1. Vias to connect top to bottom copper layers.
2. Laser ablation “skiving”
    - Cut outs in top cover layer: access to top Cu wire bond pads
    - Cut outs also in base polyimide: access to bottom Cu wire bonds
    - Cut outs in bottom cover layer: allows grounding to carbon fibre facesheet.

Tape Technologies: Pros & Cons

- Laser ablation(Elgoline) vs vias (CERN).

Laser ablation	Vias
Special processing for Cu pads before NiAu plating for wire bonding ("jet scrubbing")	Vias connect bottom Cu to top Cu. Only wire bond to top Cu. Use large enough vias and have redundant vias. Validated with destructive tests.
Laser cuts very precise openings in cover layer.	Mechanical milling → less precise openings → larger openings.
Stretch sensitive to environmental parameters	Stretch constrained by milling holes for dowel pins
Cu thickness from material.	Cu thickness from electroplating → difficult to control for large area flex

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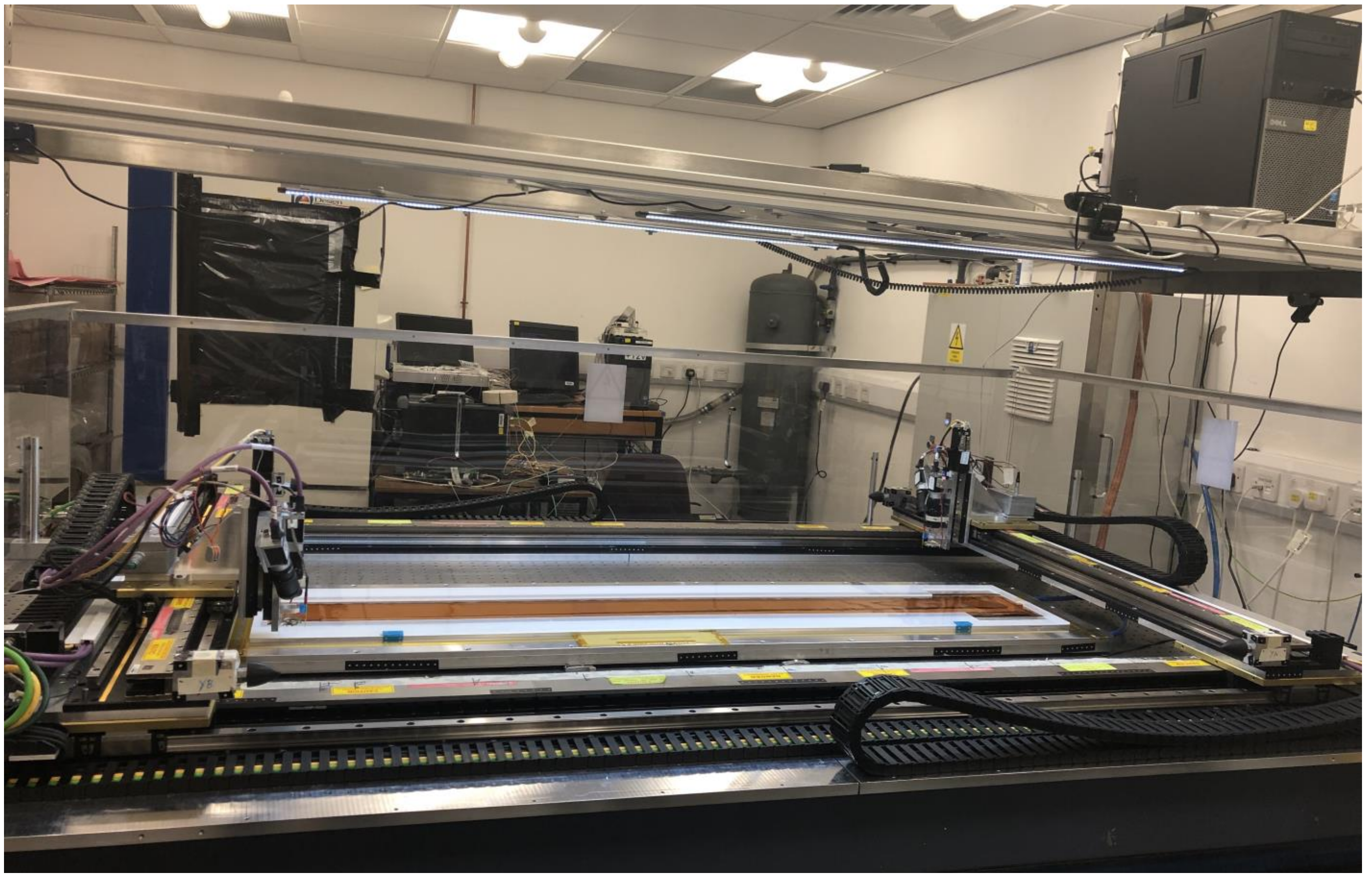
Bus Tape Testing Robot (BTTR)

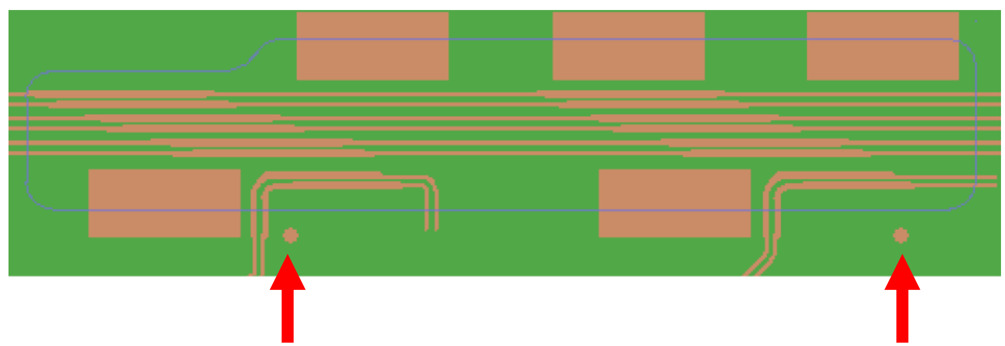
- Probes and cameras on two x/y/z stages.



BTTRs at DESY, Ljubljana, Oxford & Yale

BTTR

- Camera used to calibrate stages against Smartscope.
- Camera finds 1 mm fiducials ➔ define axis
- Camera finds 0.35 mm fiducials close to each bond pad field.
  - enables BTTR probe accurately on bond pads, allowing for distortions in bus tape
  - Metrology: stretch and distortion measured: Measured – CAD distances



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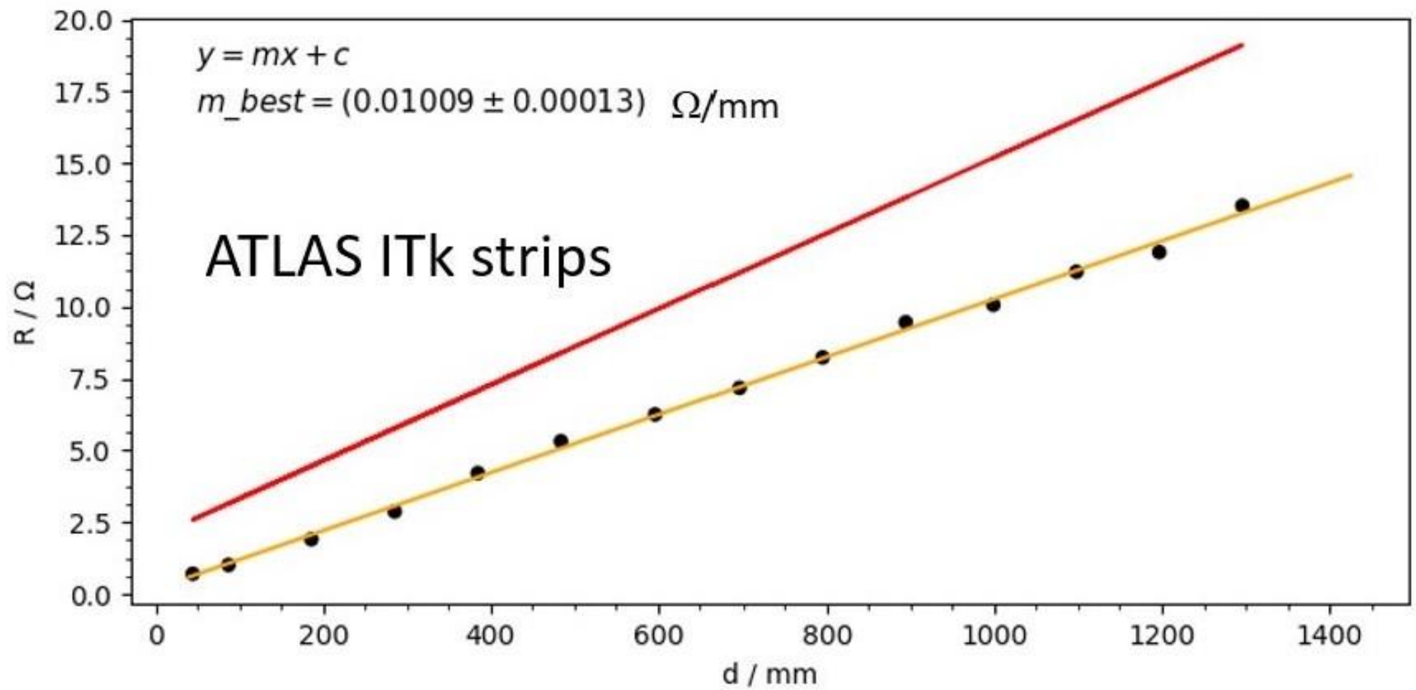
Tape Electrical Results (1)

- Measure resistance versus distance (example long 100 μm line)

  Example plot

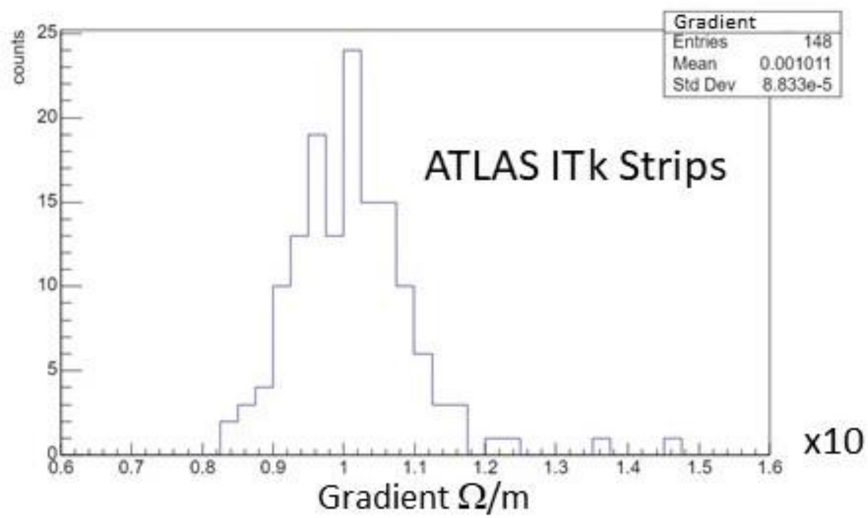


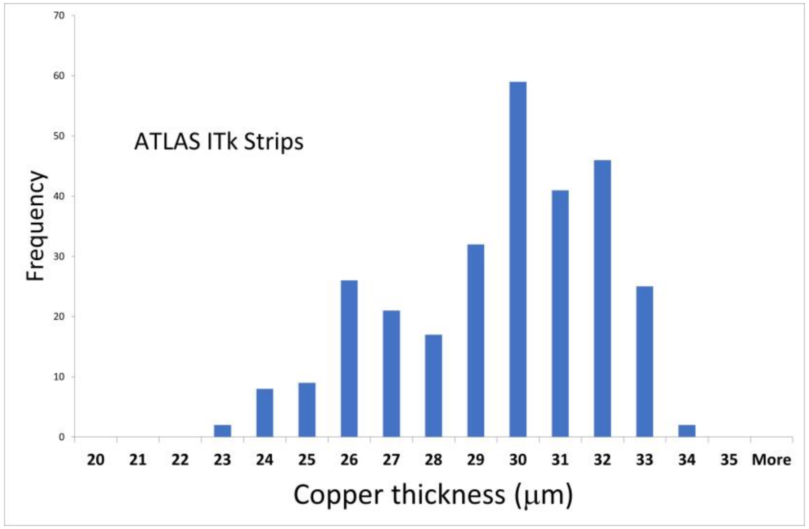
- Check all values agree with expectations within tolerances
- Fit straight line ➔ gradient.

Tape Electrical Results (2)

- Histogram gradients for stave tapes

Cu thickness



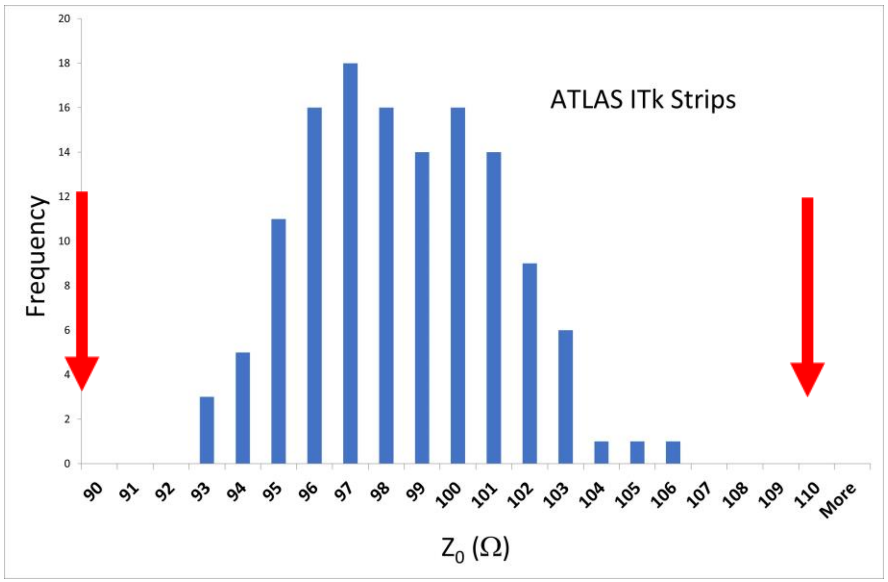


- Spread in gradient due to variation in Cu thickness (electroplating).

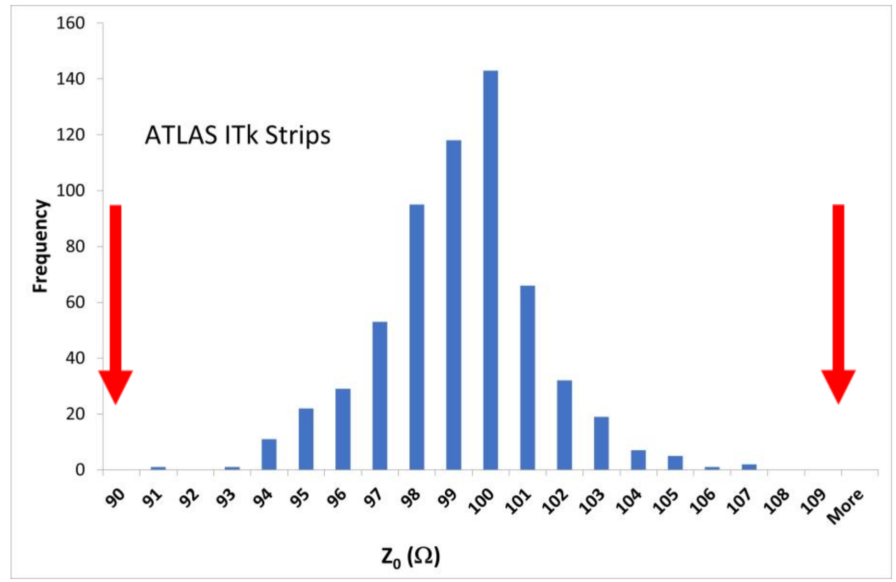
Tape Electrical Results (3)

- Impedance Z_0 measured on test trace for each tape.

Stave tapes (CERN)



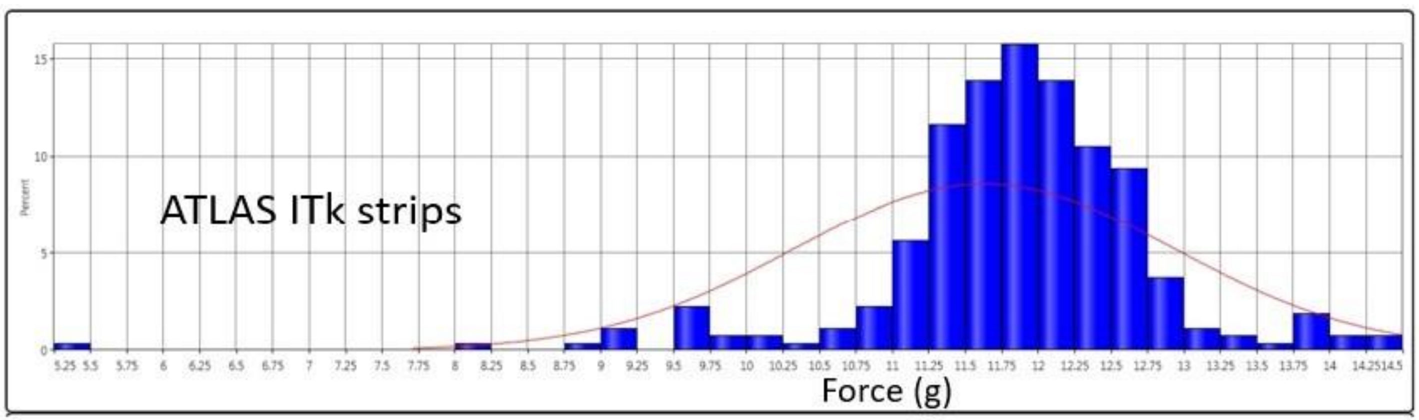
Petal tapes (Elgoline)



- Distributions reasonably centred around 100 Ω.

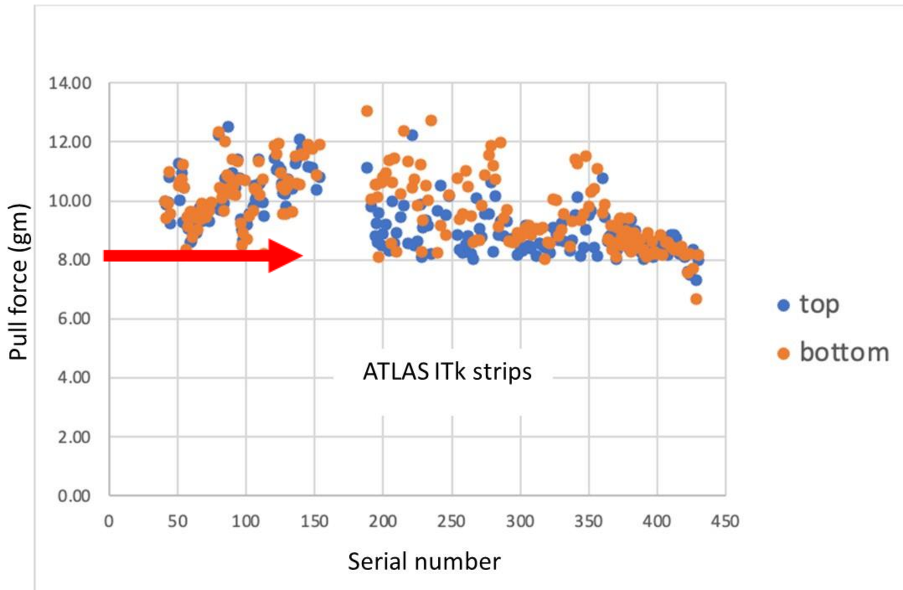
Tape Electrical Results (4)

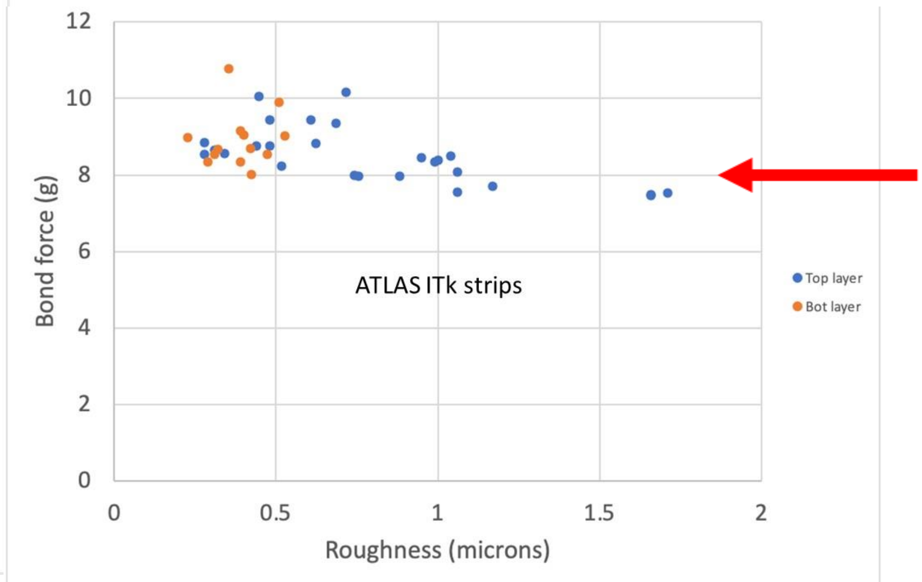
- Test bond pull strengths: require <pull strength> > 8 gm.
- Long barrel tapes: challenge is uniformity of NiAu plating over full area.
  - Initially very good bond pull strengths over most pads but worse results at edge of tape
  - Many trials, finally key improvement: tapes horizontal on Ni plating bath (more uniform chemistry)
  - Critical to check bond pads over area of tape.
  - Sacrifice one tape per batch 60 tapes. Example tape. **Mean 11.8 gm SD 1.0 gm**.



Tape Electrical Results (5)

- Petal tapes: laser ablation for bond pad openings → challenge is to achieve good surface roughness.

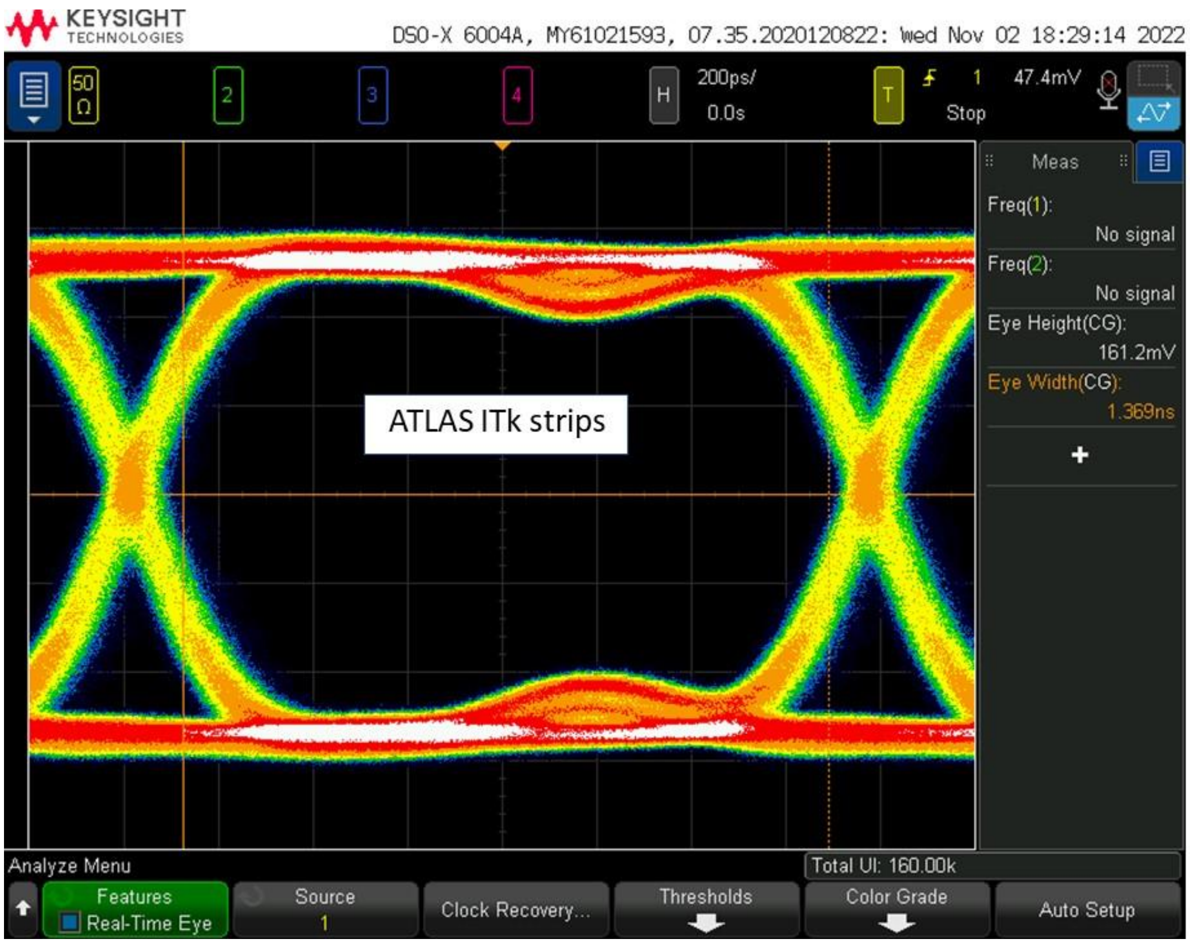




- Pull strength correlated with surface roughness → need surface roughness < 0.7 μm.

Data Transmission (1)

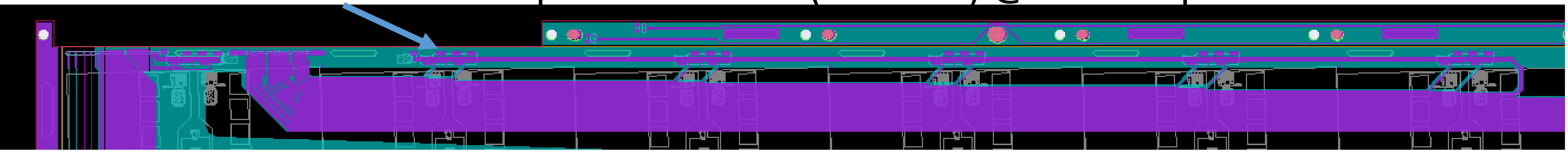
- P2P Data transmission 640 Mbps long data line.



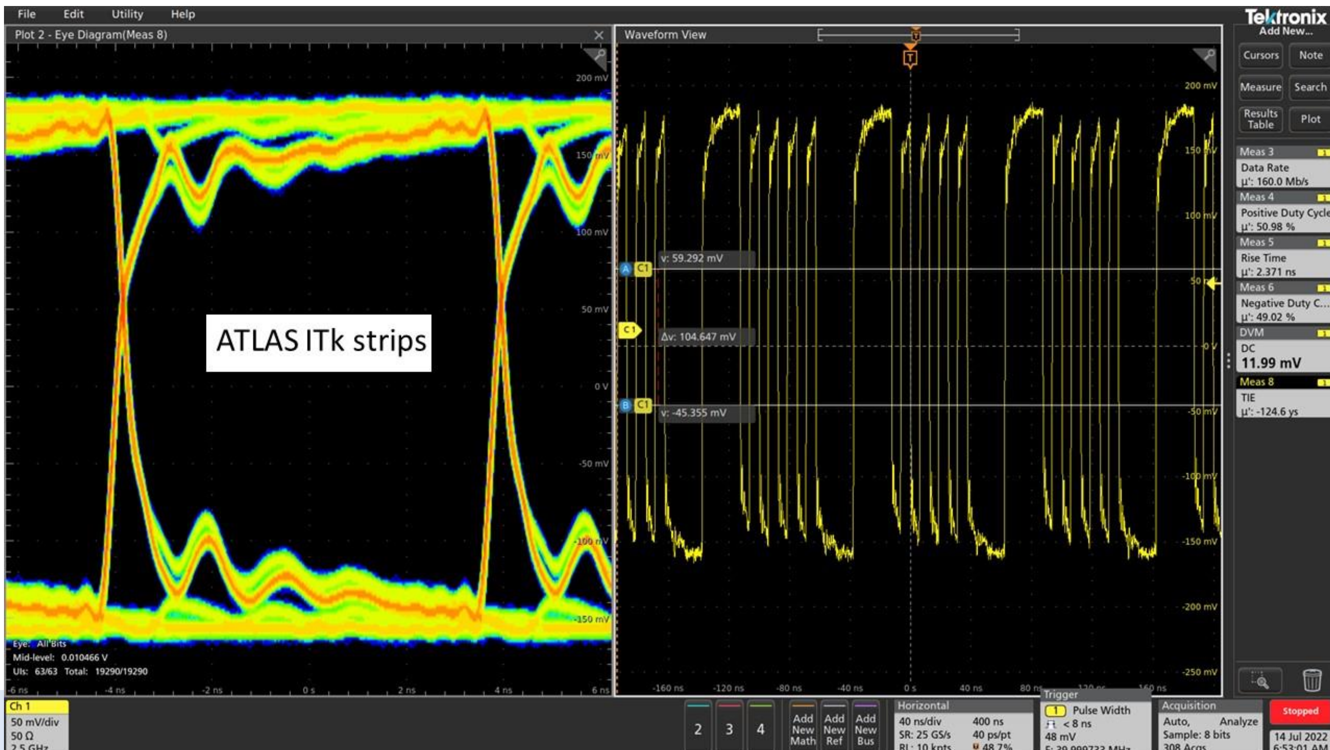
Longest line 1.4 m
Strong dispersion and attenuation but clean eye visible.

Data Transmission (2)

- Worst case multi-drop: 10 receivers (HCCStar) @ 160 Mbps



  - Reflections visible but clean eye.



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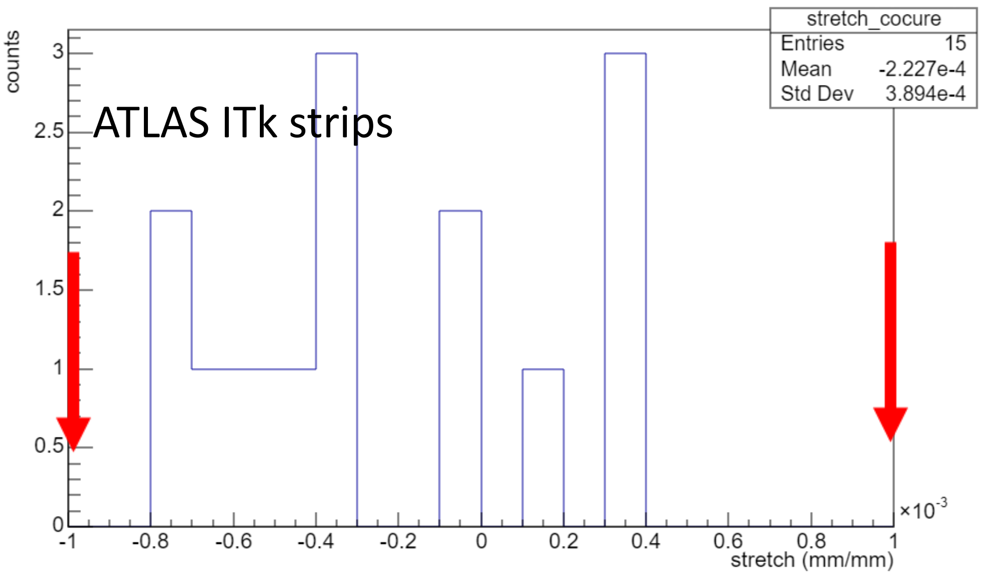
Tape Stretch

Fractional stretch in long direction (x 10^{-3})

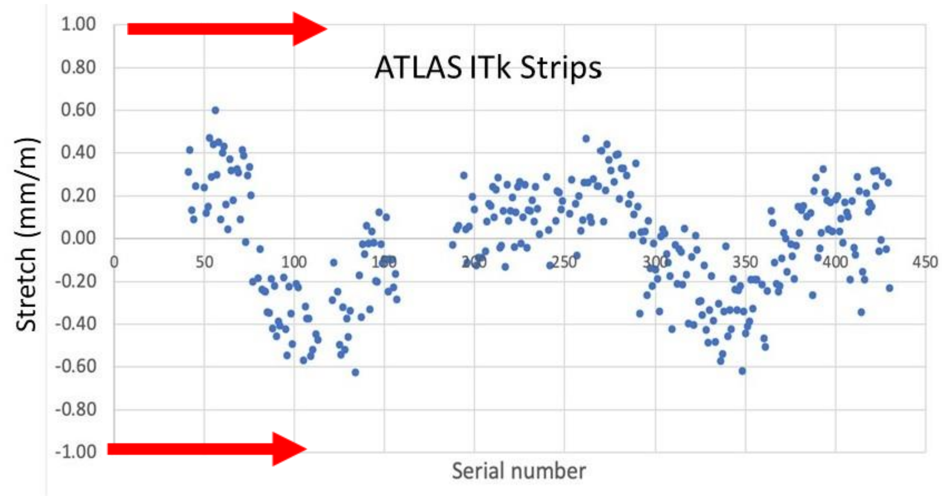
Spec **|stretch| < 10^{-3}**

- Stretch Staves (m/m)



- Don't expect long term trends (TBC)

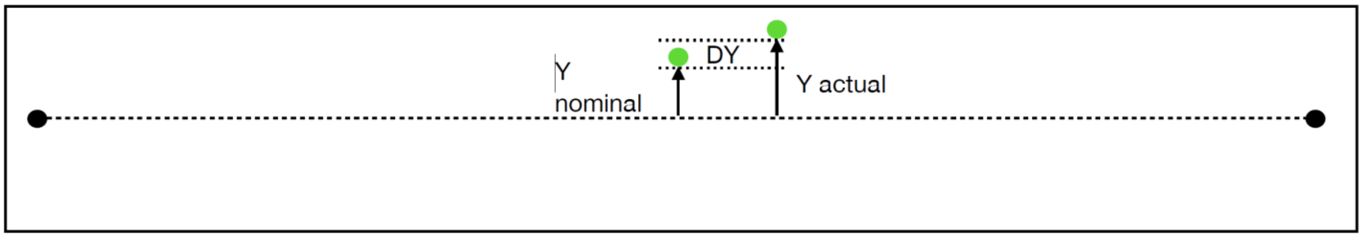
- Stretch petals vs serial number number (proxy for time)

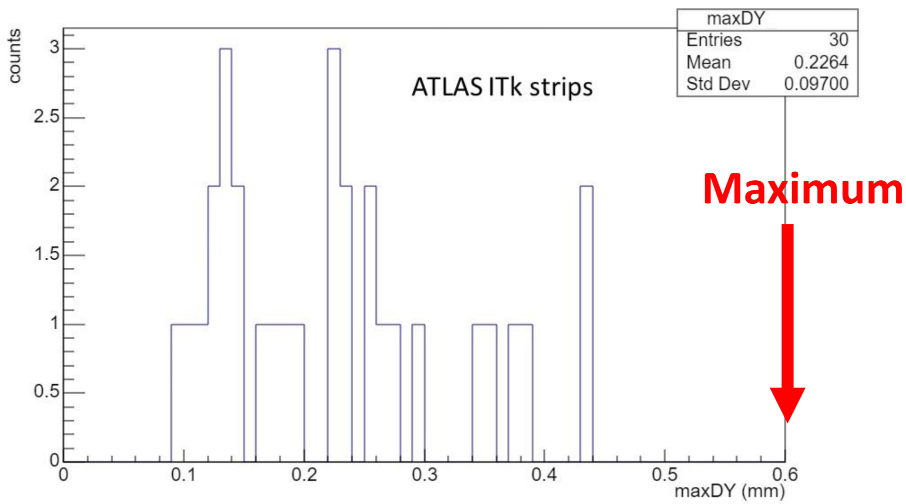


- Drifts require regular change of gerbers.

Distortions

- Distance from nominal in short direction < 0.6 mm
- Issue for stave tapes because of aspect ratio.





Measured on co-cured stave tapes (distortion not well defined bare tapes)

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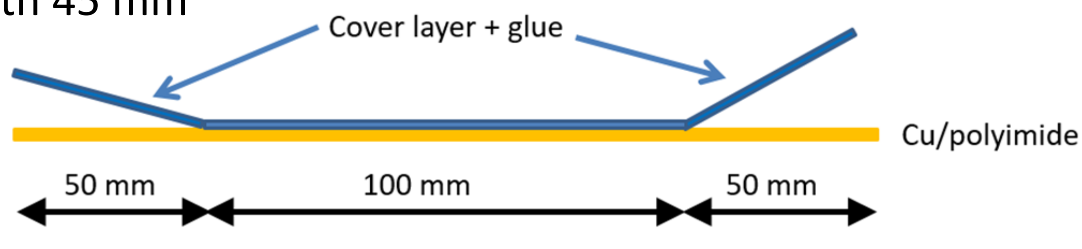
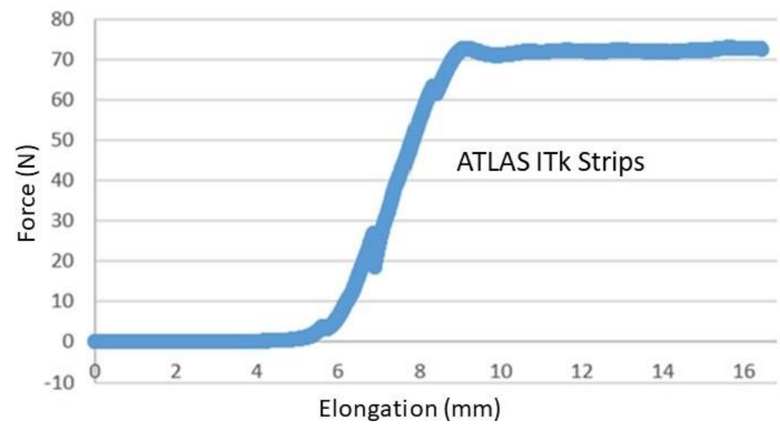
Radiation Tolerance (1)

- Check peel strength cover layer to tape for samples with and without radiation (500 kGy(Si) for barrel, 650 kGy(Si) End cap).

Width 45 mm





- Apical (base Cu/polyimide) + Krempel (Stave tapes)
  - 500 kGy(Si) INER Taiwan (array ^{60}Co sources)

Sample	Mean Pull strength (N)
Un-irradiated	76 ± 5
Irradiated	75 ± 3

Radiation Tolerance (2)

- Good radiation tolerance validated with sources at Sandia (US) and 6 MeV Linac (Oxford oncology).
- Very poor radiation tolerance for samples with Taiflex as used by proposed industrial partner for stave tapes.
  - Surprise because earlier tests had shown good radiation tolerance.
  - Material not qualified for radiation tolerance ➔ **need to check every batch**.
  - Stave tapes (CERN) are using Apical + Krempel.
- Similar tests with Kapton material used for petal tapes (Elgoline)
  - Good radiation test results for 650 kGy(Si).

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Summary

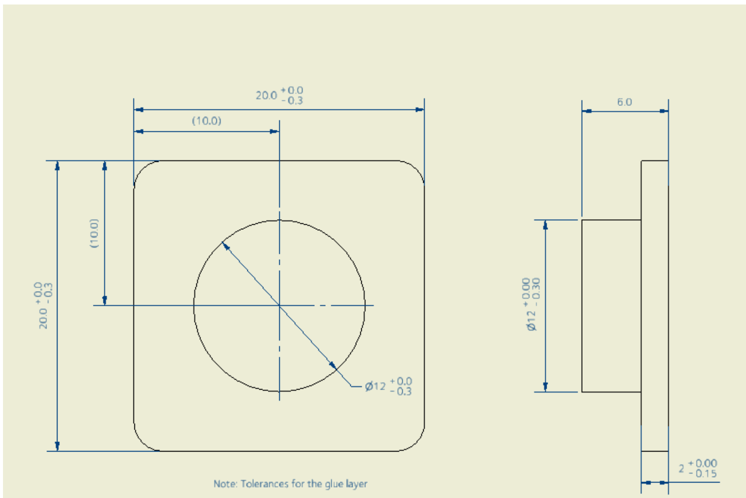
- Challenges for ATLAS ITk strip bus tapes
  - Long tapes with narrow track and gap lines
  - Electrical and dimensional requirements
  - NiAu plating large area tapes
  - Radiation tolerance
- Pros and cons of laser ablation vs vias.
- Stave and petal tapes long development time but now in production!
- **Questions Welcome!**

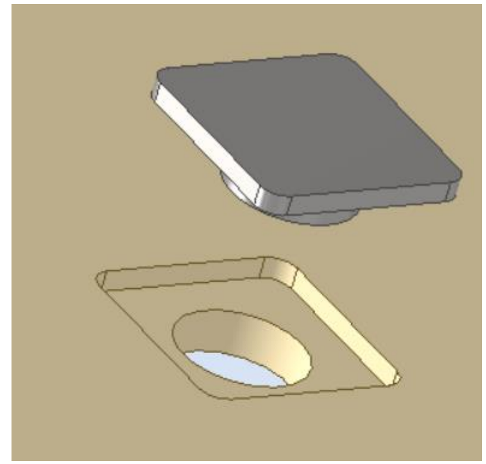
Backup

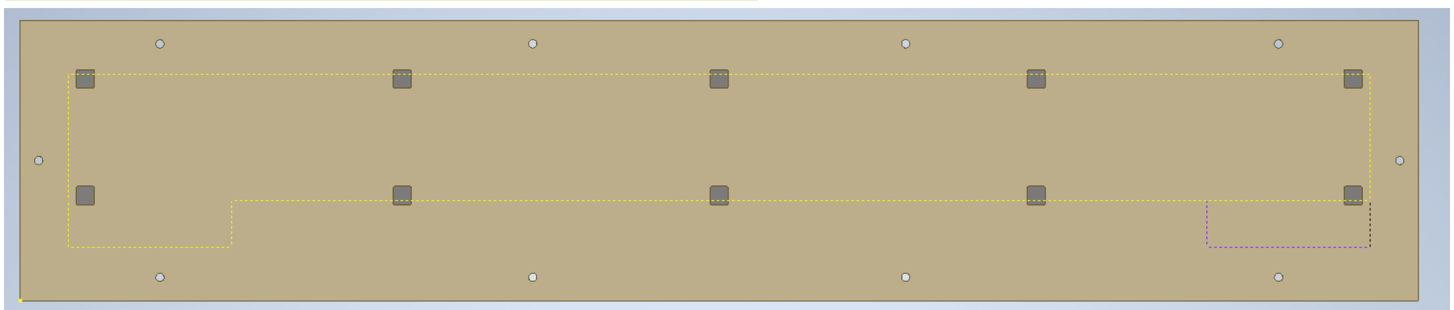
Laser Ablation

- Two Cu layers on adhesiveless PI.
- PI + glue cover layer
- Laser ablation “skiving” ➔
  - Cut outs in top cover layer: access to top Cu wire bond pads
  - Cut outs also in base PI: access to bottom Cu wire bonds
  - Cut outs in bottom cover layer: allows grounding to carbon fibre facesheet.

INVAR inserts in 6 mm thick carbon fibre jig

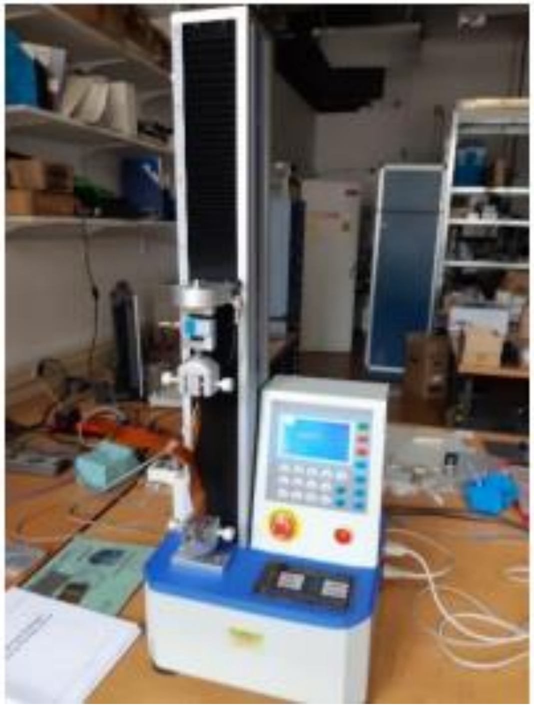




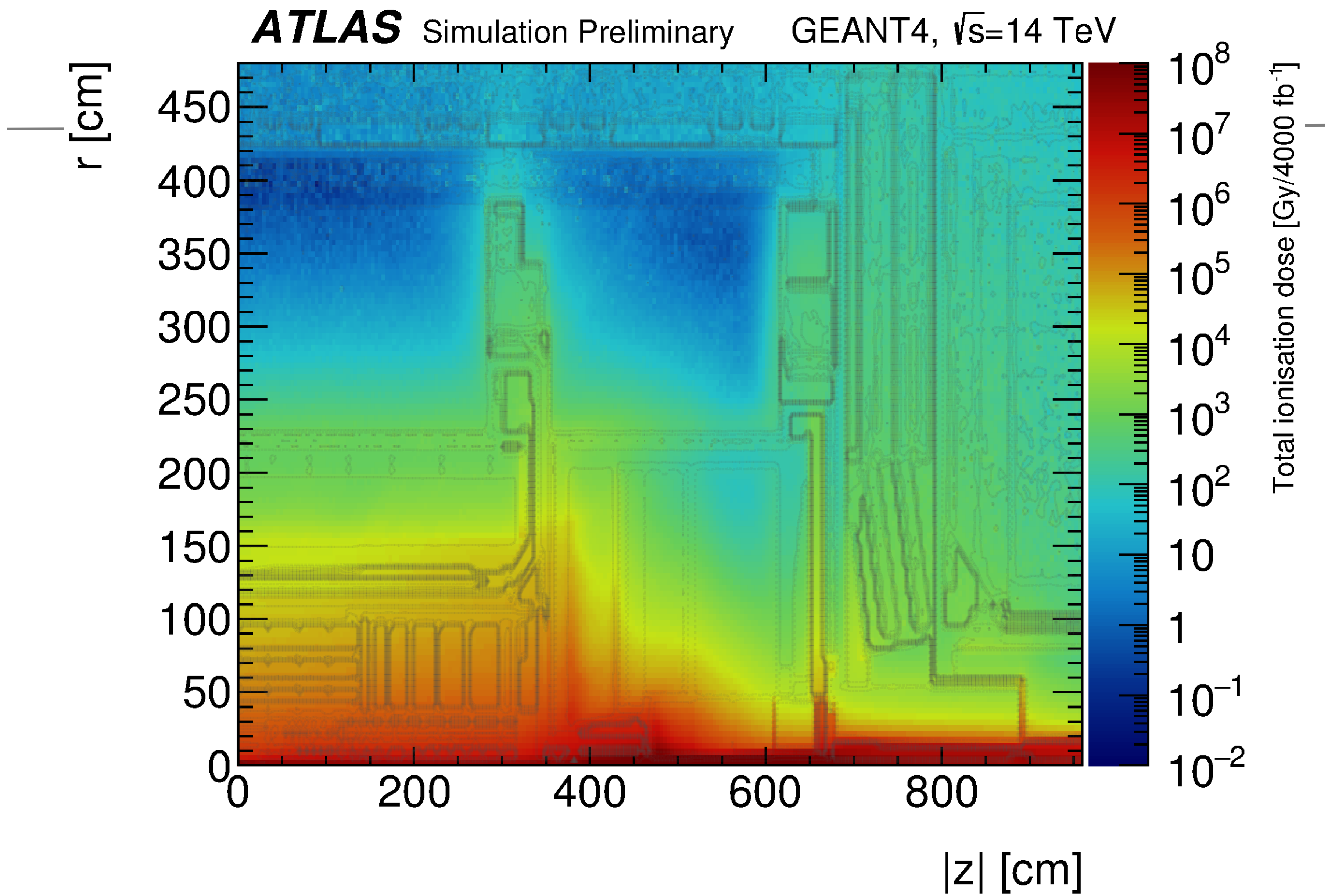


10 off 6mm dowel holes drilled after the inserts are glued.

Pull tester for radiation hardness studies

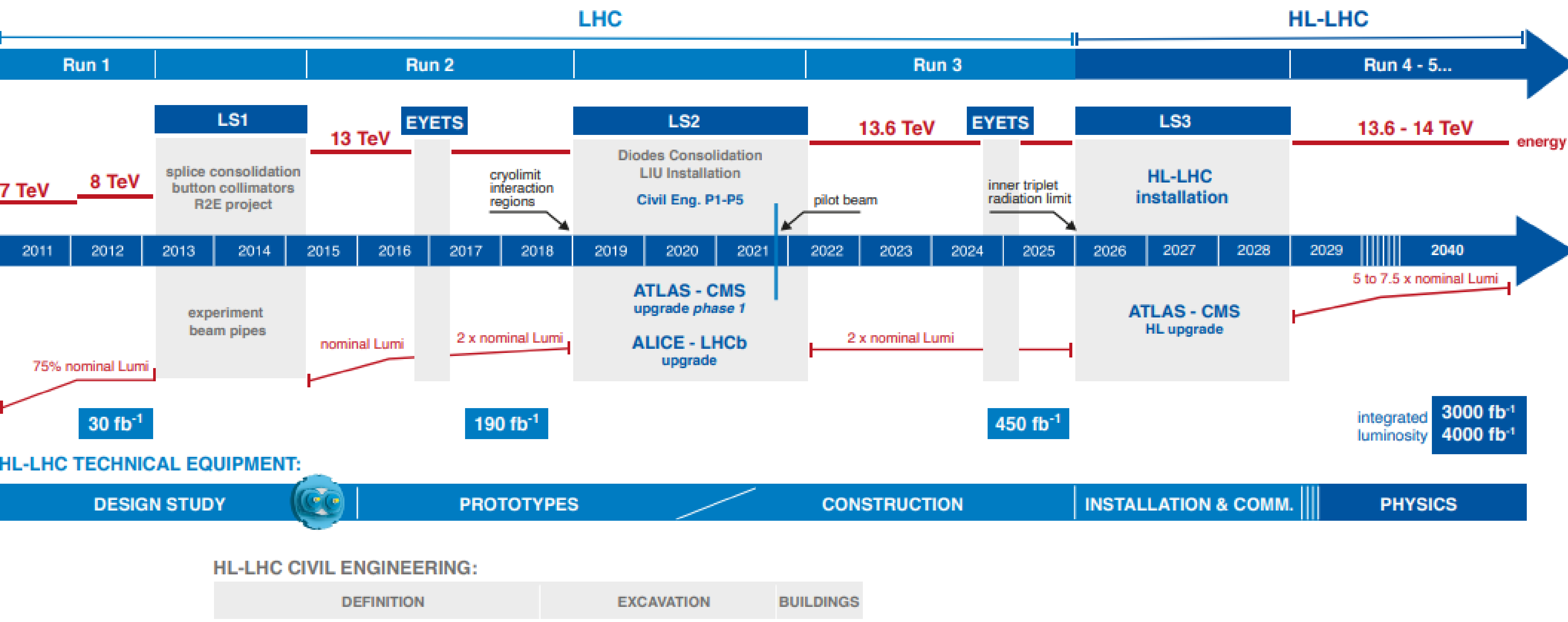


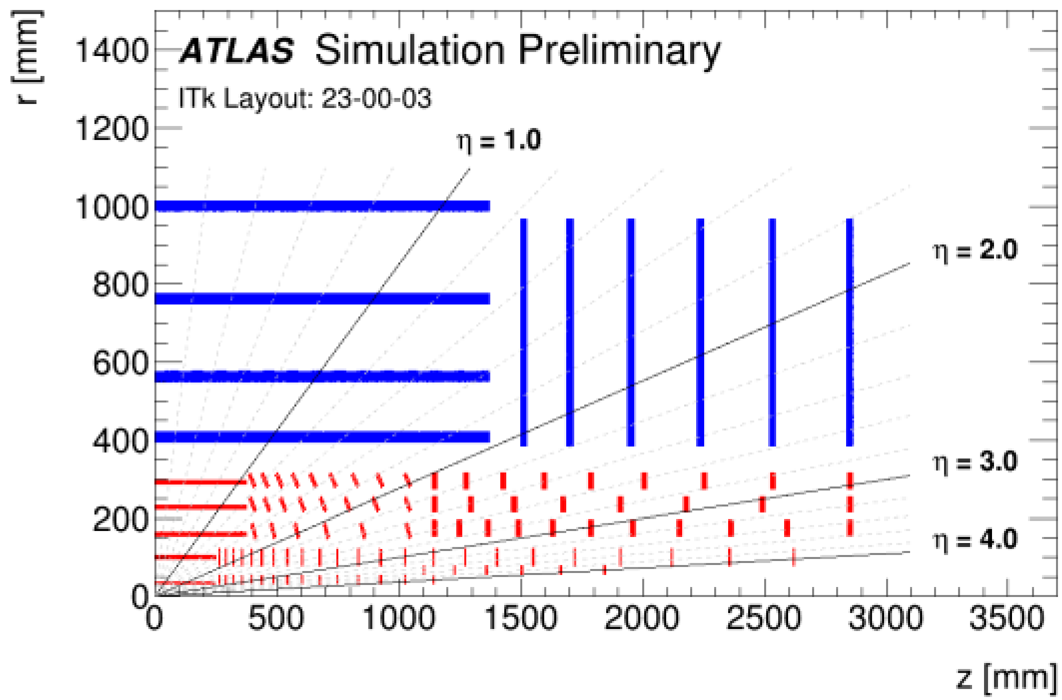
Pull tester at JSI Ljubljana.
Similar machine at Oxford.
Tests also performed at LBL.

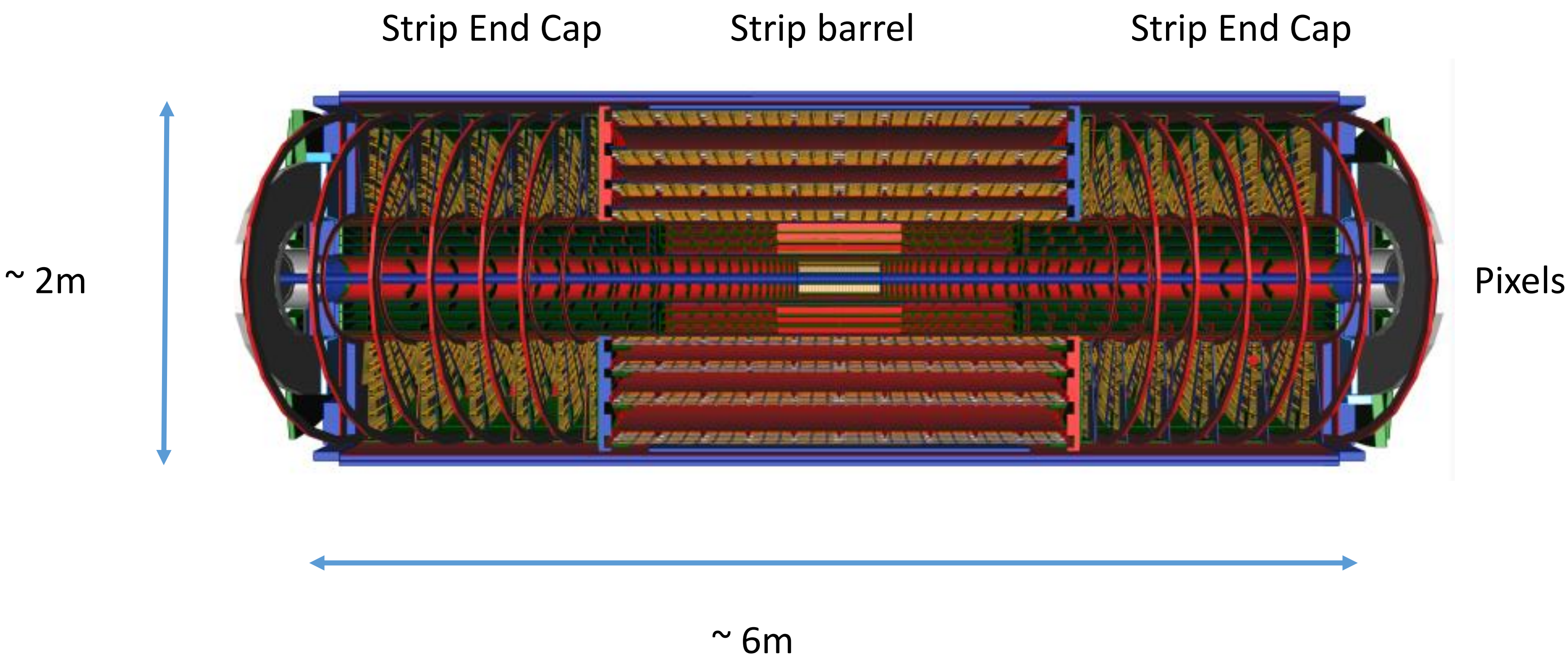


ATLAS Simulation Preliminary
GEANT4, √s=14 TeV
r [cm]
|z| [cm]
Total ionisation dose [Gy/4000 fb⁻¹]

LHC / HL-LHC Plan




ATLAS Simulation Preliminary
ITk Layout: 23-00-03
η = 1.0
η = 2.0
η = 3.0
η = 4.0
r [mm]
z [mm]
0
200
400
600
800
1000
1200
1400
500
1000
1500
2000
2500
3000
3500


Strip End Cap
Strip barrel
Strip End Cap
~ 2m
Pixels
~ 6m