Low Mass Design of the ATLAS Strip Tracker Upgrade

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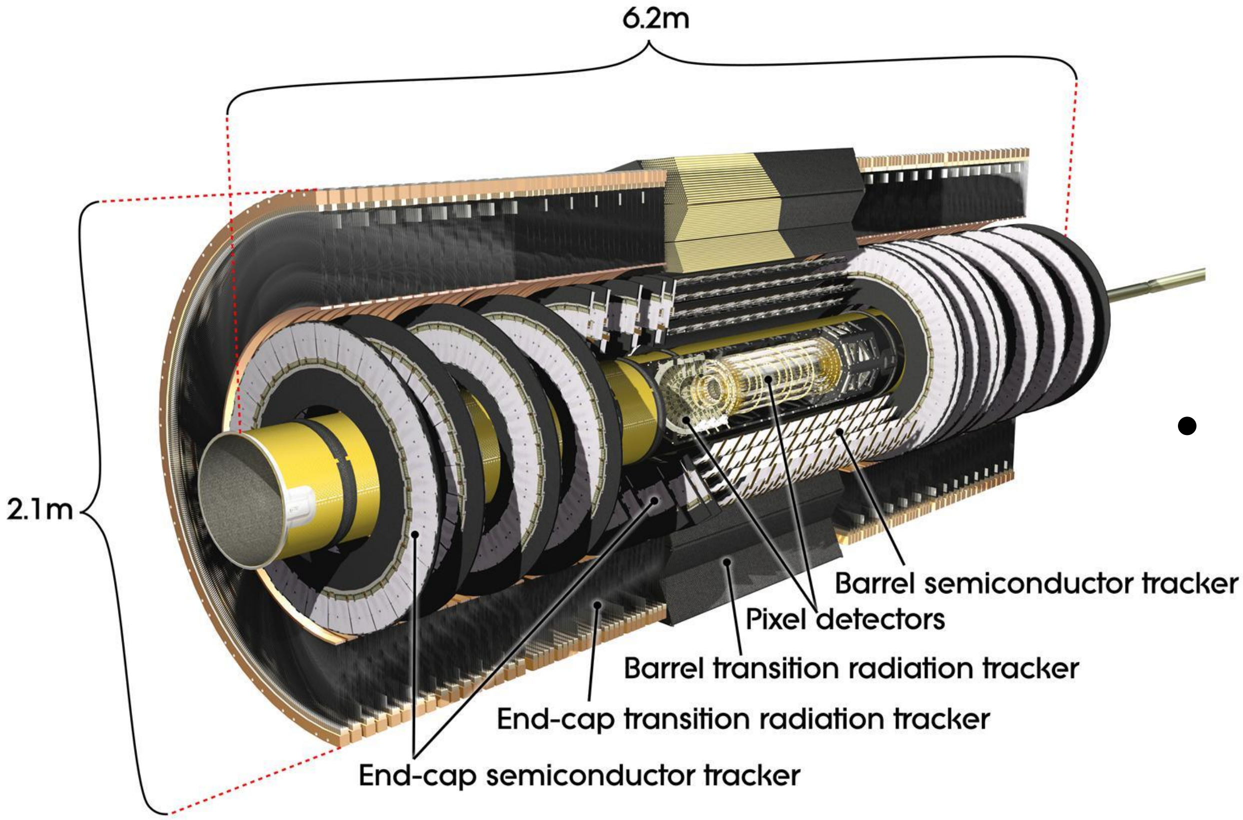
Outline

- Current SCT
  - Barrel and endcap design
  - Assembly
- Motivation for upgrade
  - More, more, more…
- Local Support Design & Implementation
  - Design overview
  - Modules, Mechanics & Services
  - Materials
- Summary

(Almost) none of the work presented here is mine!

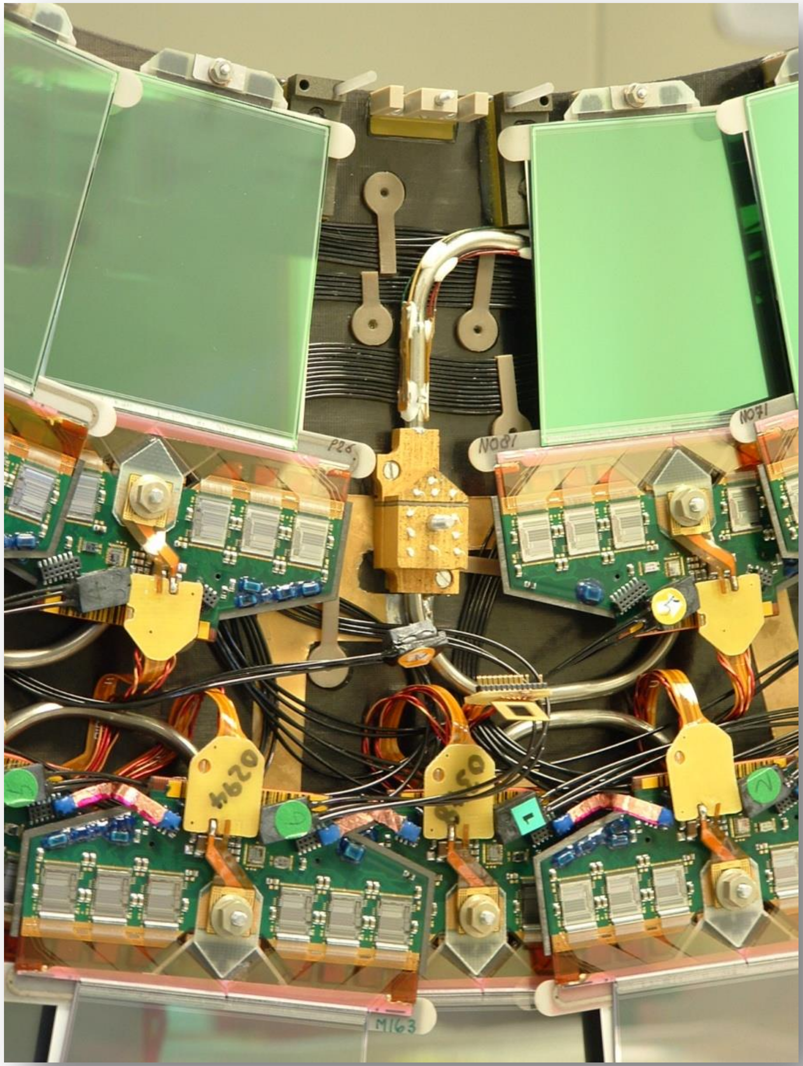
The ATLAS Inner Detector



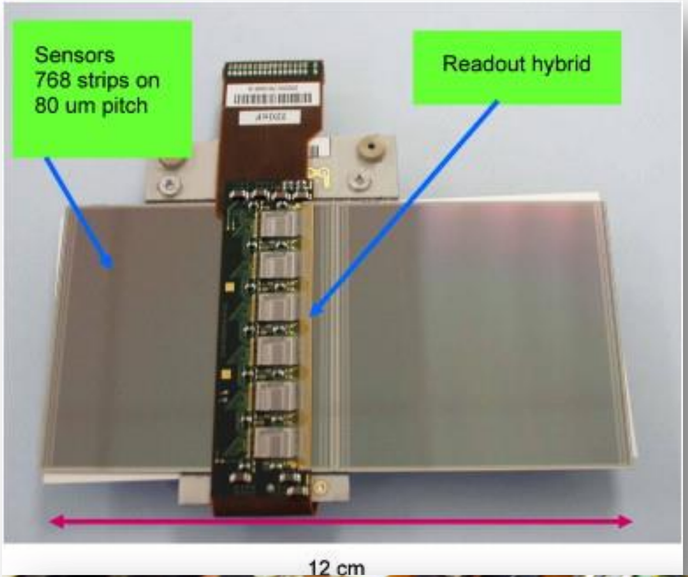
- ID
  - Pixel
  - Silicon Strips
  - TRT
- Silicon Strips
  - Barrel
    - 2112 modules on 4 barrels
  - Endcaps
    - 2 x 988 modules
    - 2 x 9 disks

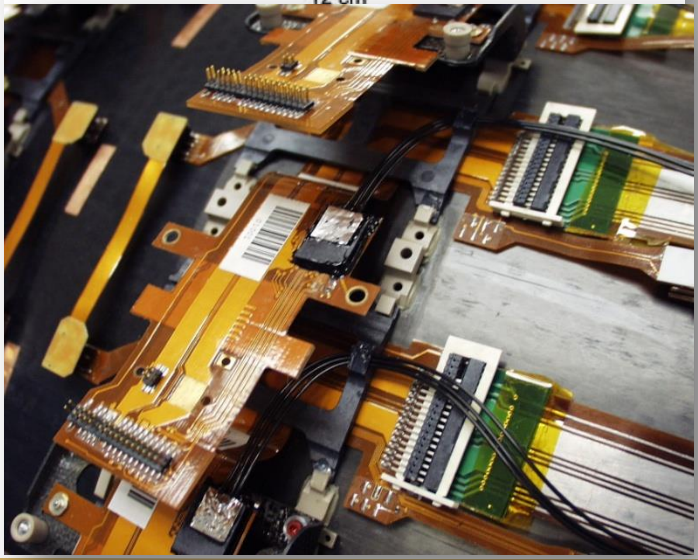
Endcap SCT System Design

- Silicon modules arranged on disks in (up to) 3 rings
  - 52 / 92 / 132 modules per disk
  - Radial positions defined by hermeticity requirements
  - Double-sided modules with silicon rotated at /- 20mrad to axis
- Hybrids mounted at end of silicon
  - Outer modules have hybrid at narrow end to maximise active radius
- Separation of FE ASIC and Silicon heat paths
  - Ensures optimal cooling of silicon to inhibit thermal runaway
- Module Interfaces
  - Thermal Contact
  - Electrical power
  - Redundancy
  - Plug-able Opto converters



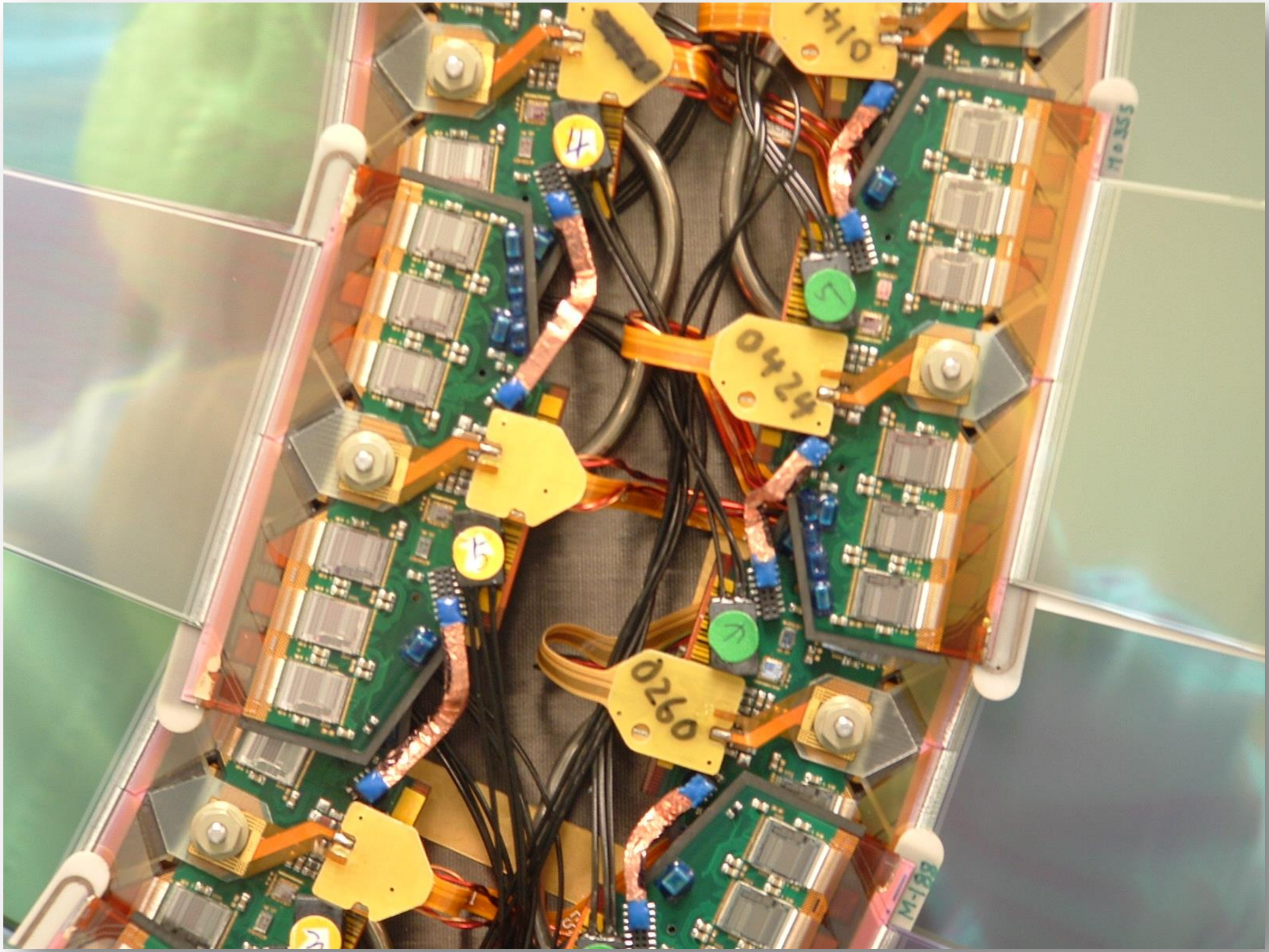
SCT Barrel System Design



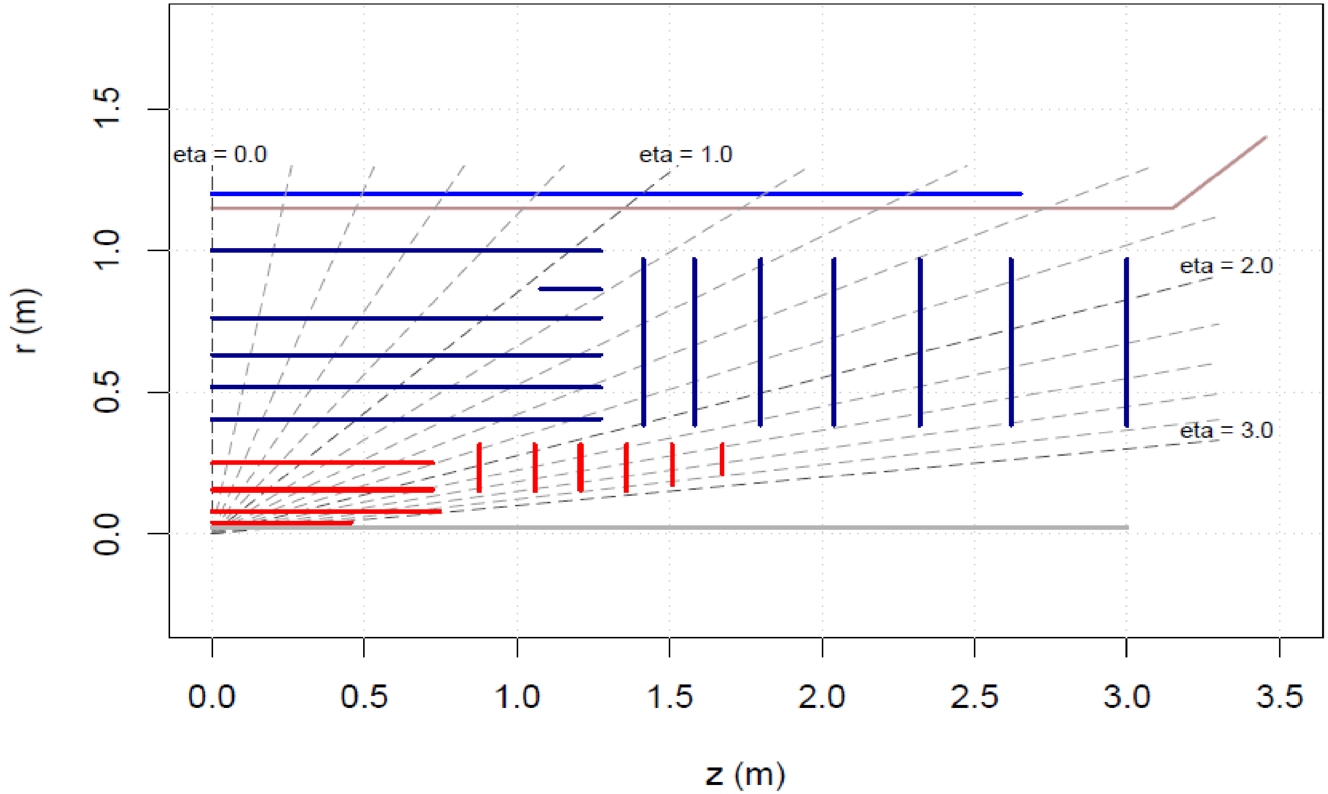


- Mid-mounted wrap-around bridged hybrid with single-connector electrical interface
- Single edge cooling via baseboard
- On-cylinder 'dog-leg' for
  - Power interface to low-mass cable
  - Redundancy
  - Opto conversion

Motivation for Change!



Phase-2 All-Silicon Tracker



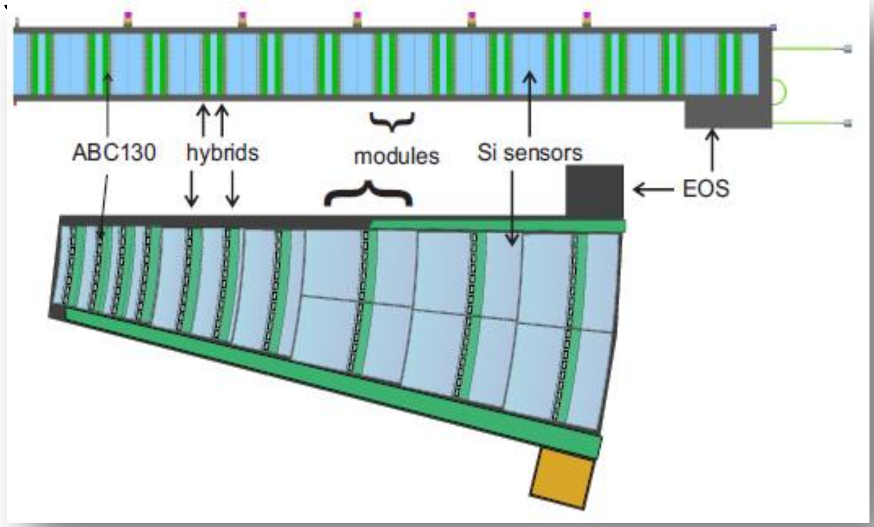
- 4(pixel) + 5(strip-pairs) = 14 hits
- Strips: 200m^2 (5 ½ barrel layers + 2x7 disks) (**x3.3**)
- Pixels: 8 m^2 (**x4.7**)

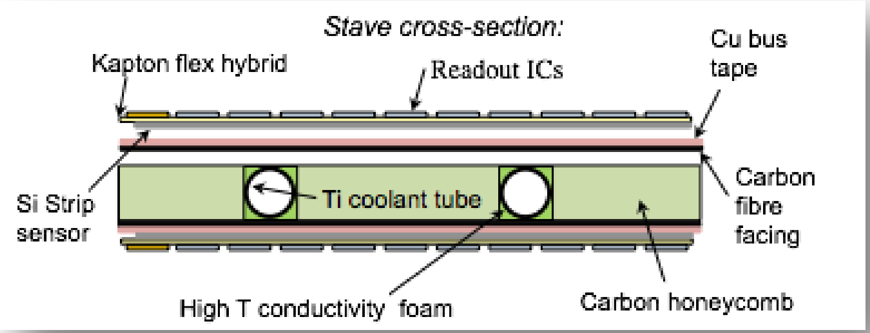
Strip Tracker Design Drivers

- Positional Stability
  - ~few μm stability over timescales of ~days
- Thermal Stability
  - Good margin of safety with respect to Thermal Runaway
    - Tolerant to CO_2 evaporation temperature rise of ~ 5°C
    - Tolerant to sensor power increase of x2
- Radiation tolerant
  - Radiation dose is substantially greater than SCT but, crucially, less than current ATLAS Pixel doses
    - Sets the scope of materials choices
- Low integrated $\%X_o$
  - How low is low?
  - Improve on current SCT: 3%/layer in barrel and 3.5%/layer in EC
- Industrial-scale Assembly
  - Factor 3.3 increase in sensor area, x2 in modules, x40 in carbon-fibre structures (1,000 vs 10+4+10)
  - Community is smaller than in 2000 (Physicists have data!)

Local Supports

- Low-mass carrier for groups of modules
  - Stave: 2x13 modules
  - Petal: 2x6 modules
- Integrated services
  - Cooling
  - Electrical Connections
  - Data concentrator (EoS)
- Module Interfaces
  - Adhesive
  - Wirebonding
- Global Support structure for final positioning

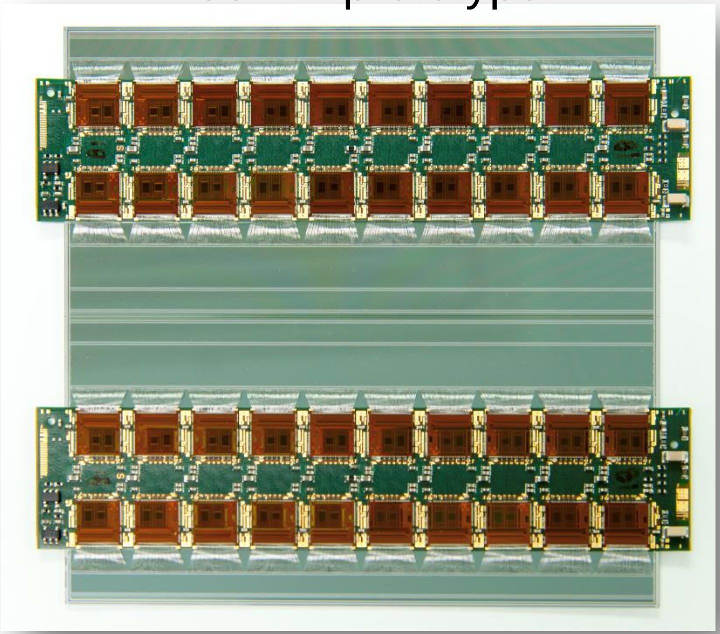




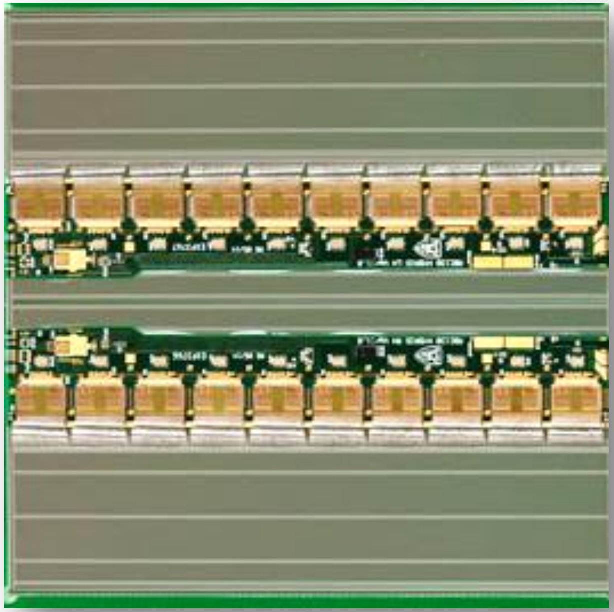
In what follows I discuss barrel staves – petals will be similar

Stave Module Design

250 nm prototype



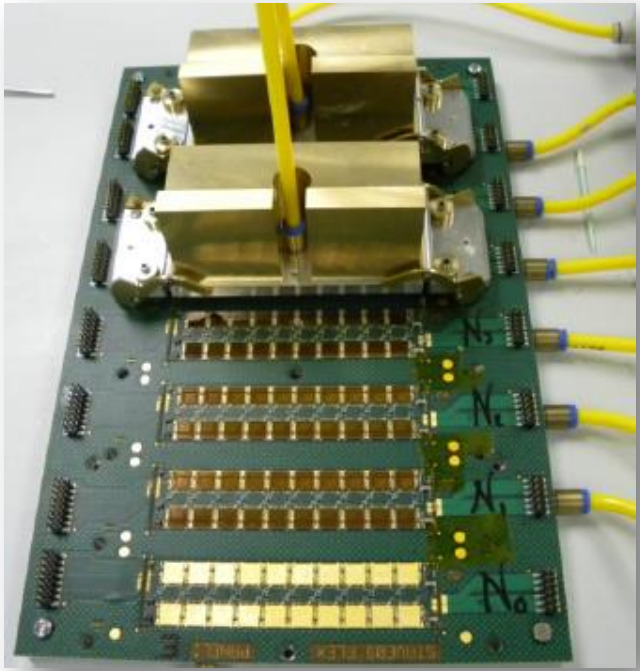
130 nm prototype



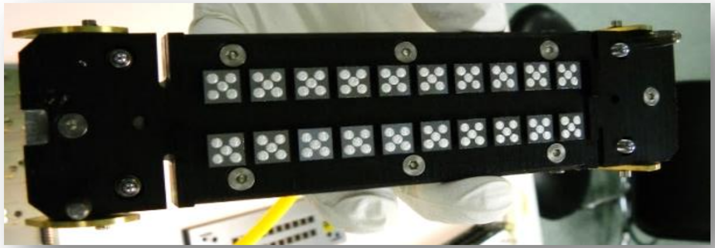
- Low-mass (substrate-less) hybrids glued directly on to silicon sensor
- Major initiative was moving from 128 to 256 channel ASICs
  - Collaborative effort between sensor, ASIC, and hybrid designers important
- Reduced material by 40%, hybrid bonding times by ~60%, module bonding times by ~30%
  - Reduced estimated production time by ~1 year

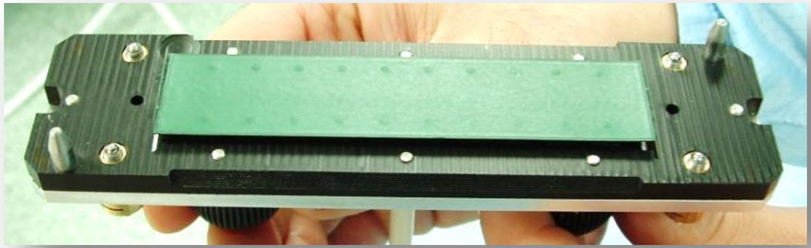
Hybrid Mass Production

- Conservative design rules
  - Maximize yields for 20,000 parts
  - Enable multi-vendor capability
  - Push down cost
- Design for Throughput in Assembly
  - Processing in 8-hybrid panels
  - Automated SMD placement and soldering of passive components
  - Mass attachment/wire bonding of custom ASICs
  - Test tokens to monitor track and via quality during production
- Hybrid Testing
  - With final ASIC set (ABCn-130nm, HCC, power), all hybrids in the panel tested with one data I/O and one power connection



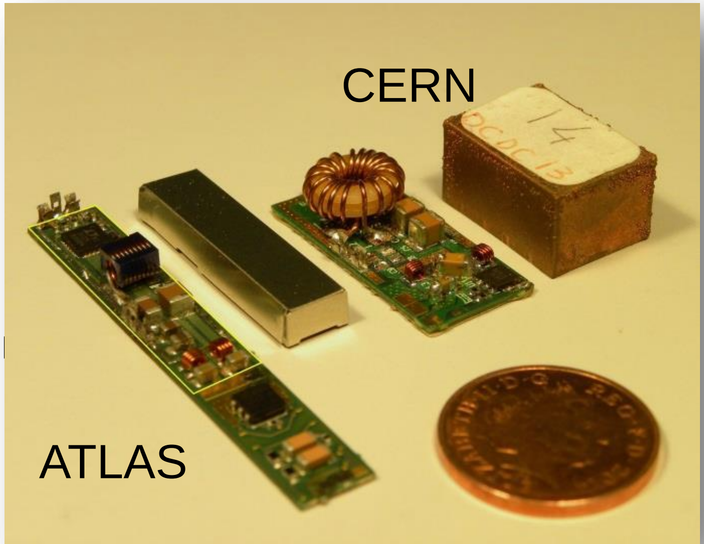
Panel dimensions: 300mm x 200mm
Hybrid dimensions: 24mm x 107.6mm



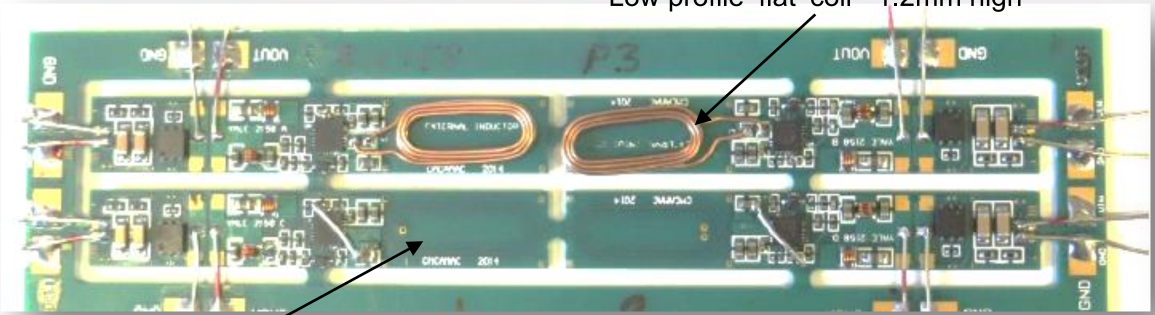


Module Powering

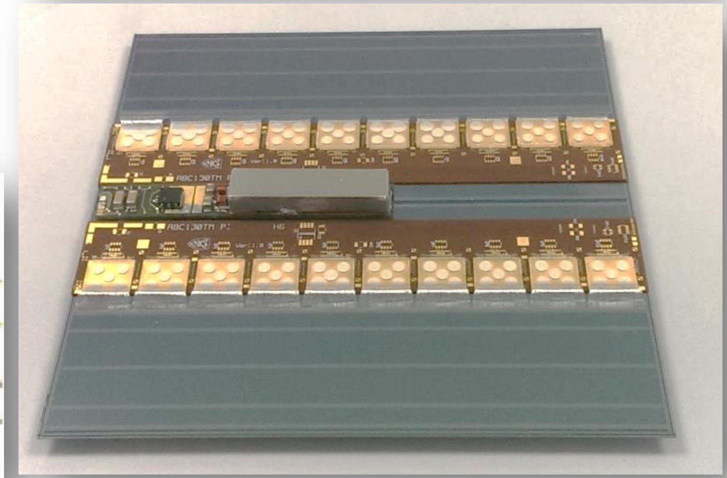
- Issue is that reducing I^2R in power distribution requires high V, low I but ASICs run at low V
- Baseline powering choice is DC-DC
  - DC-DC base layout and FEAST ASICs provided by CERN PH-ESE
- Development of ATLAS Strip stave specific geometry (PCB and coil) to enable mounting on-silicon
  - Material reduced by shrinking packaging (from 0.1% to ~0.05% X_0 per module)
  - Custom flat coils are important to reduce height which drives clearances within a layer



Low profile ‘flat’ coil ~1.2mm high

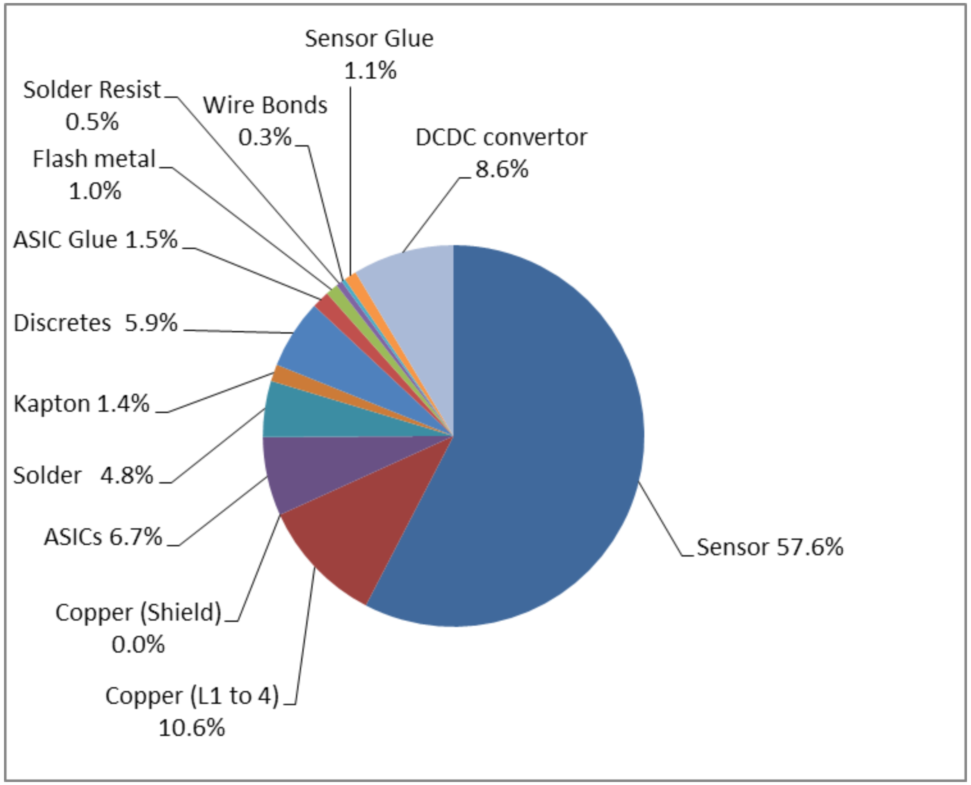


Embedded coil

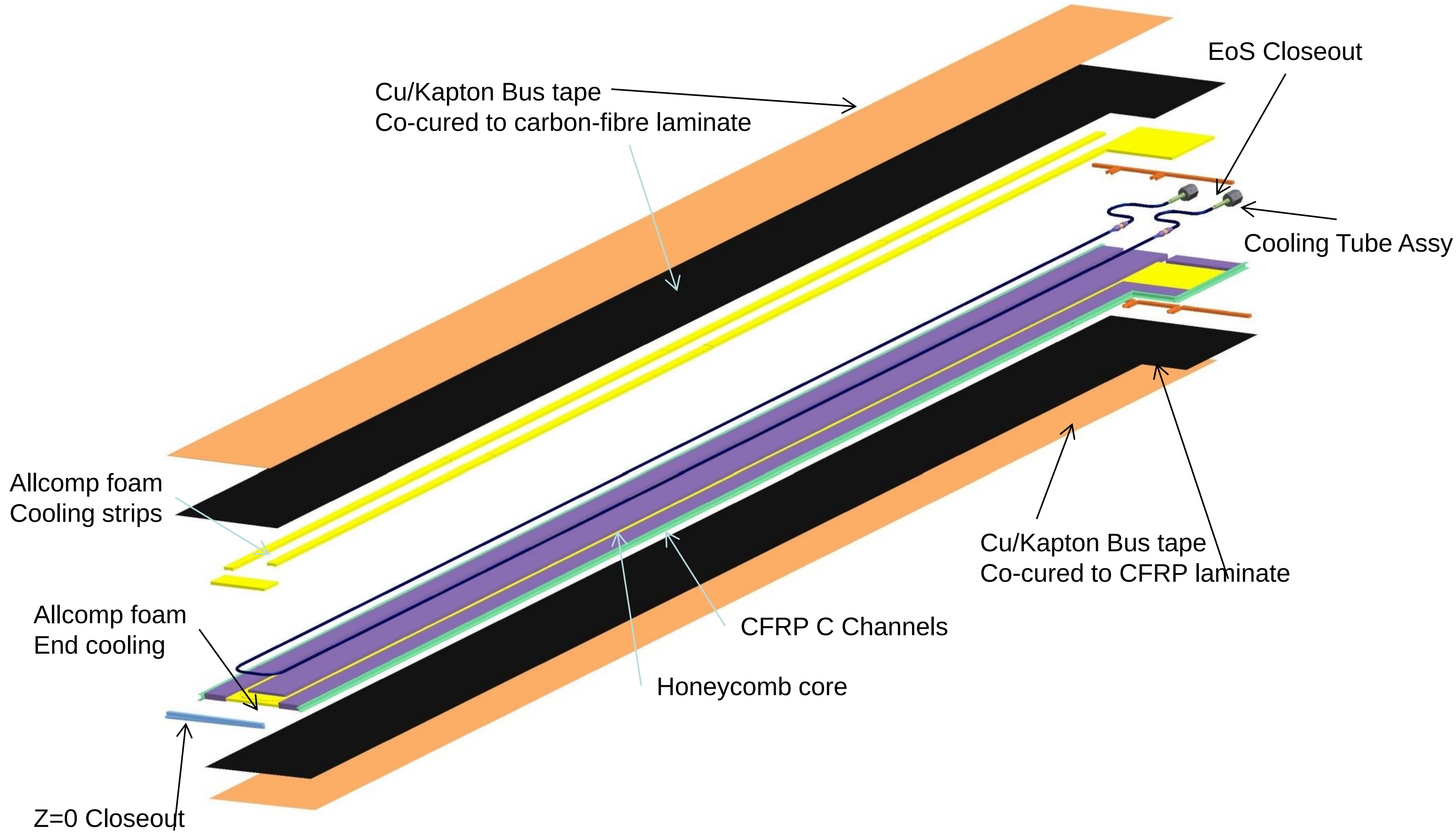


Module Radiation Length

- Module Material = 0.59%X_o
  - Long-strip module (outer two layers) has single hybrid so material = 0.51%X_o
- Dominated by:-
  - 0.32mm thick silicon sensor (58%)
  - Copper circuit (11%)
  - DCDC (9%)
  - ASICs (7%)



Stave Detail

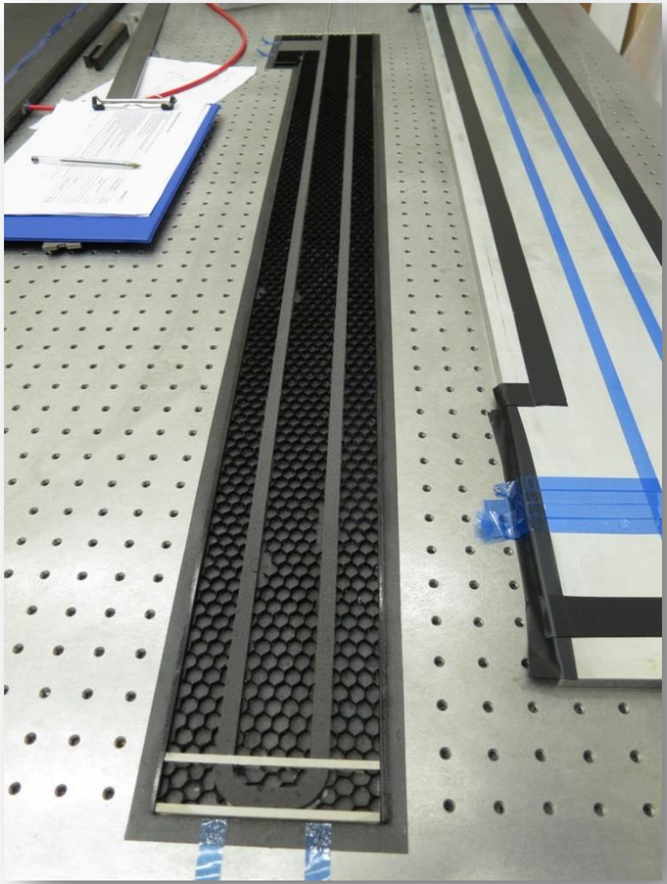


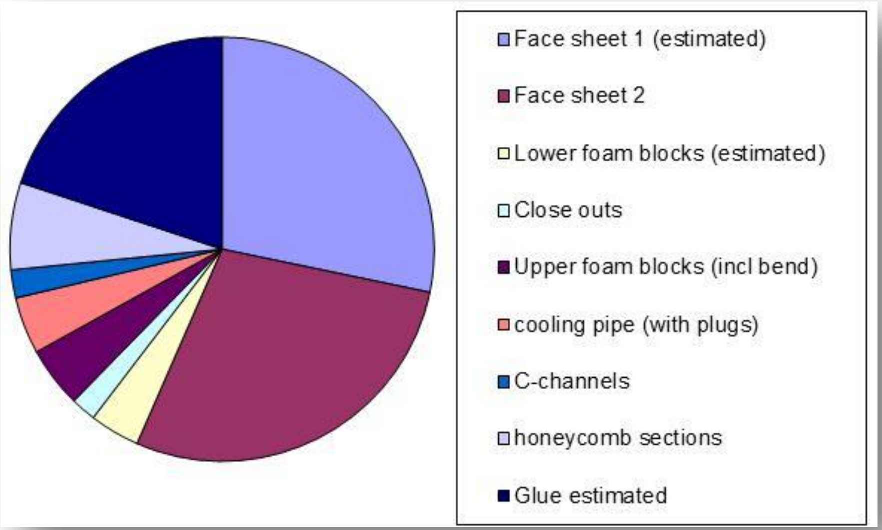
Stave Construction and Materials

- Stave is a sandwich structure with;
  - 2 co-cured face sheets
  - A central core manufactured from Ultracor honeycomb & Allcomp thermally-conductive foam
- Petal structure is essentially the same

Component	Material	Remarks
Face sheet	K13C2U with Tencate EX1515 Cyanate-ester Resin ($45 g/m^2$ 40%RC)	3 ply 90/0/90 (0.15mm) co-cured to a Cu/kapton bus tape (0.2mm)
Honeycomb Core	Ultracor CFRP 1/4 to 3/8" cell size 2.0 to 3.5 lbs/cuft	thickness 5.2mm (machined/as-supplied)
Thermally Conducting Foam	Allcomp K9, 130ppi $K \sim 40 W.mK^{-1}$	thickness 5.2mm
Cooling tube	Titanium CP3	2.275 x 0.125 wall
End Closeouts	PEEK CF30 / LCP	Machined / molded
C Channels	Carbon Fibre	Pre-preg + resin infusion
Adhesive	Hysol EA9396	+BN (30%) for Th. Cond.

Plank #9 manufacture



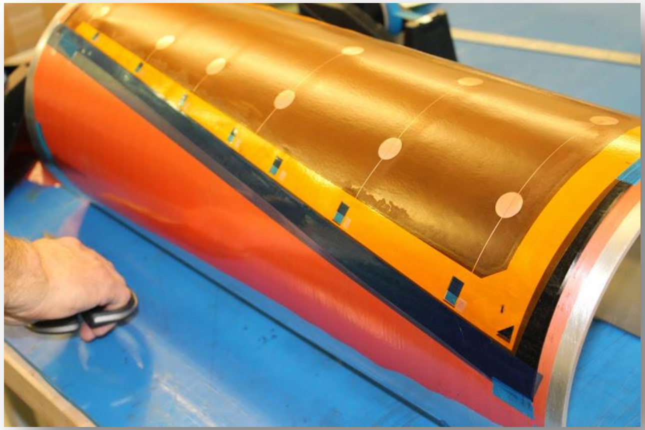


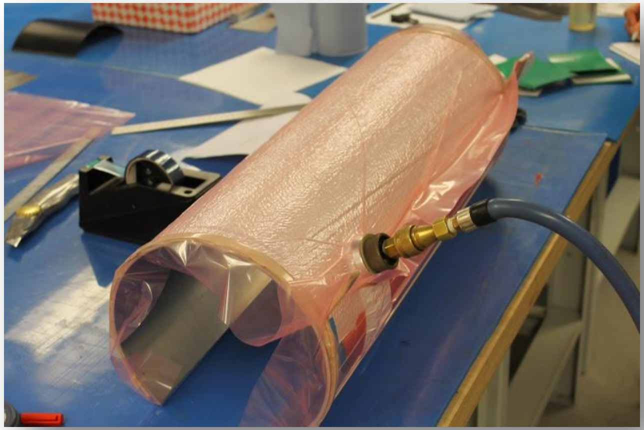
Total weight of stave 330.37g

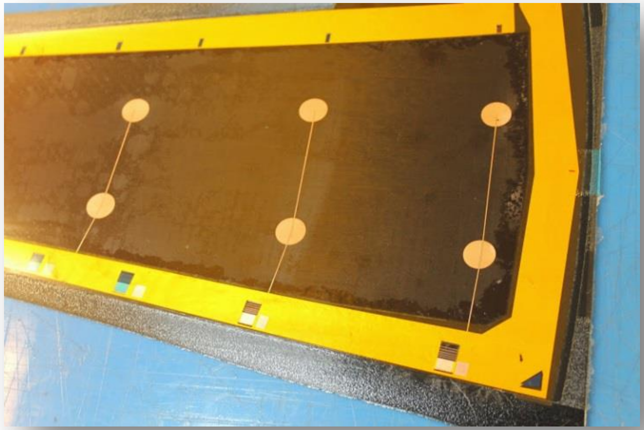
Viehhauser & Yang

Co-curing (example from Petal)

- Method to attach Cu/Kapton bus tape to CFRP face sheet using resin in pre-preg
- Complication is the elevated processing temperature (120°C) and large differential CTE (20ppm)
- Needs curved jig & curved pressure plate to get best results

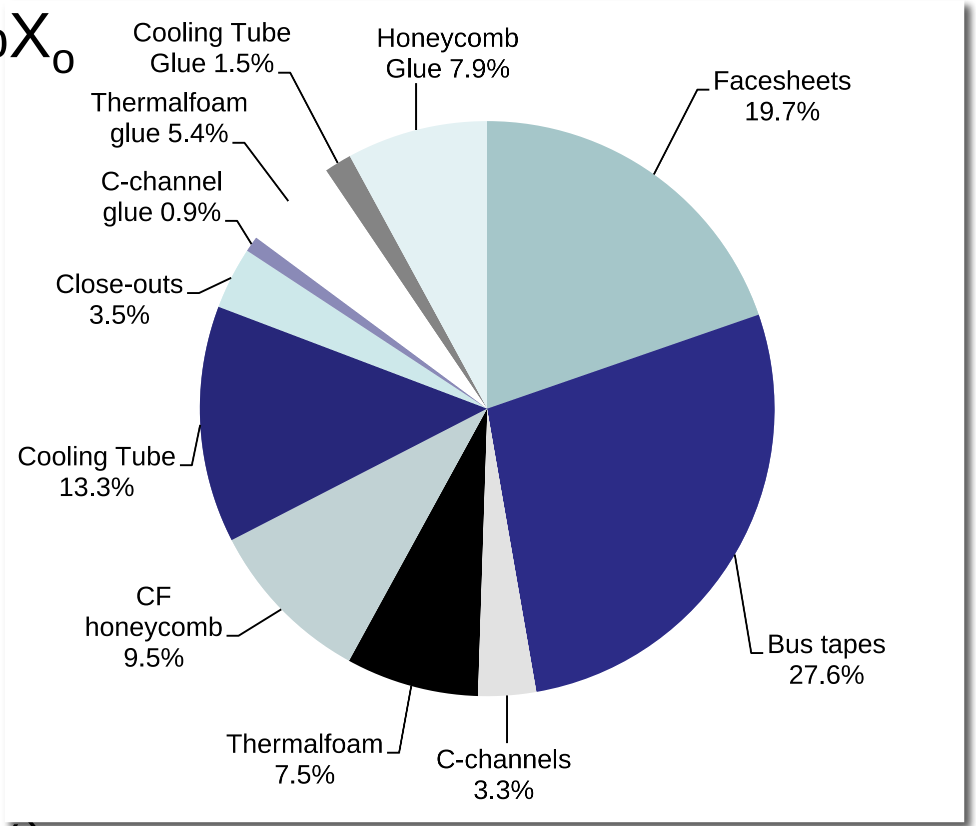






Stave Core Radiation Length

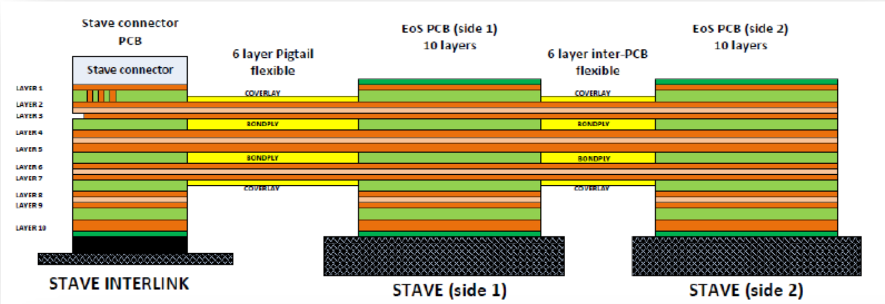
- Stave Core Material = 0.66%X_o
- Excluding:-
  - Insulating breaks
    - Titanium/alumina (0.071%)
  - End-of-Structure Card
  - Modules
- Dominant Contributions
  - Bus tapes(28%), face sheets(20%), cooling tube (13%)
  - Adhesives (16%)

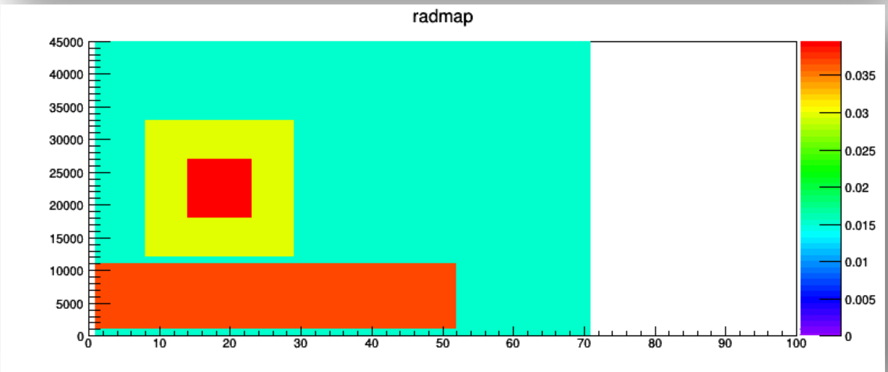


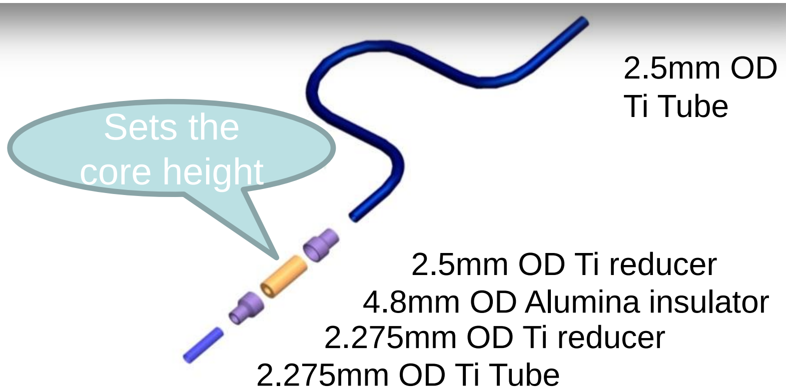
End-of-Stave Region

- End-of-Structure Card
  - Electrical services (pig-tail to Axon connector)
  - Optical interface (Lightpeak)
  - Multi-later PCB with Cu/Kapton flex wrap-around
  - Material ~ 2%X_o in general rising to 4% in specific regions

- Insulating Breaks
  - Ensures electrical isolation of stave from services tree / other staves
  - Alumina isolator brazed to titanium end-caps
  - Material (smeared over 1 module) = 0.071%X_o

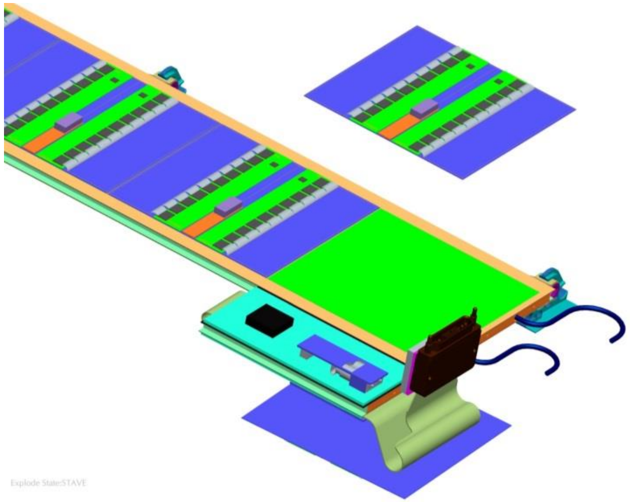


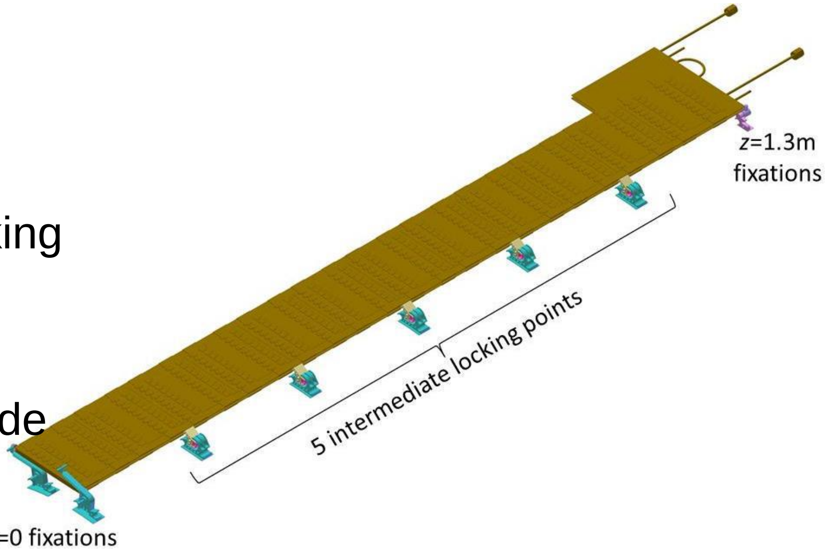




Interfaces

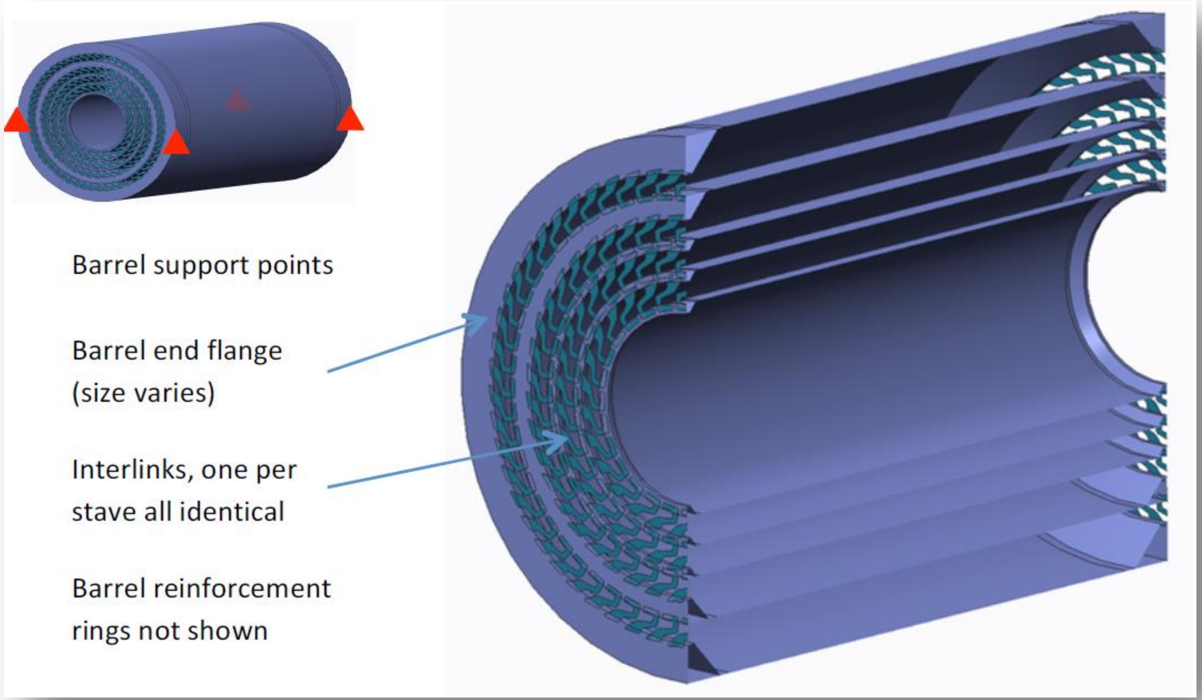
- Module
  - Glued to stave core with SE4445 (+ silver epoxy)
    - 0.1mm over full area = 0.03%X_o
  - Wire-bonded to bus-tape
- Services
  - End-of-Structure card glued to stave core & wire-bonded to bus tape.
  - Control & data output via optical interface
  - Power & temperature interlocks via electrical connector
- Support Cylinder
  - Single-edge mounting using discrete locking points
    - 5 locking points + stave fixations = 0.08%X_o
  - Allows for 'end-insertion' in to pre-assembled array of support cylinders inside global (7m long) outer cylinder





Barrel Support Structure

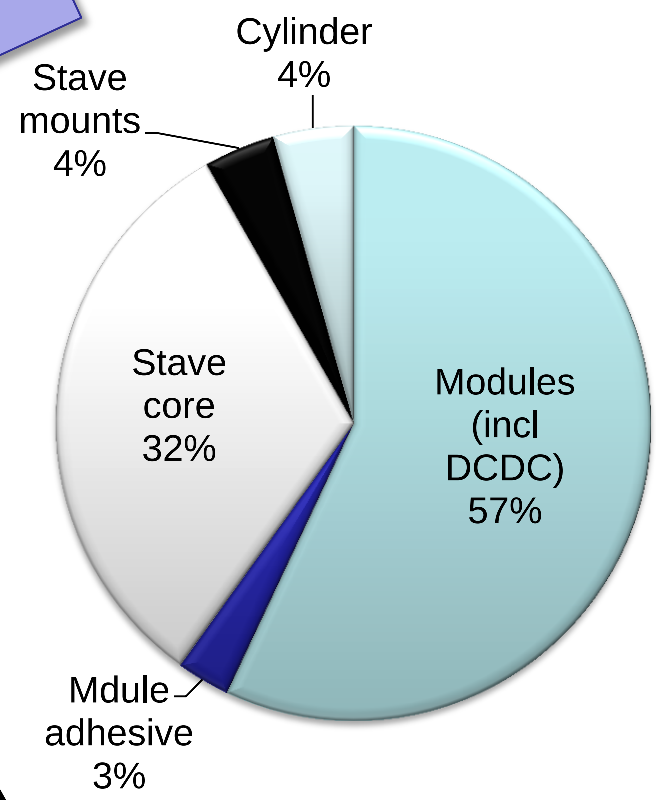
- Cylinders
  - Single skin (+ rings)
  - 4-ply (0/45/-45/90) (0.248mm)
  - Material ~ 0.09%X_o
- Flanges
  - End-flanges with internal bonded web
  - Material unknown
- Interlinks
  - One per stave
  - Material unknown



Putting it all together

Component	$\%X_o$
Modules (incl DCDC)	1.18
Mdule adhesive	0.06
Stave core	0.66
Stave mounts	0.08
Cylinder	0.09
Sum	**2.07**

ONLY AT Z=0 & NROMAL INCIDENCE



NB: **Material identification, tracking & optimisation is an on-going iterative process so presented numbers will be wrong, old, optimistic. Wait a year or two!**

Summary

- Material optimisation has been a constant theme driving ATLAS Strip Tracker development

- Material savings made through
  - Integrated design (Local support cores)
  - Exploiting Technology (256 channel, 130nm ASICs)
  - Being bold (gluing hybrids to silicon, gluing modules to local support cores)

- Whilst … keeping in mind the production challenges
  - Simple modules to ensure efficient mass production
  - Local supports to ensure longer parallel production paths
  - Simple module to structure/services interfaces to enhance reliability