The Front-End Hybrid for the ATLAS HL-LHC Silicon Strip Tracker

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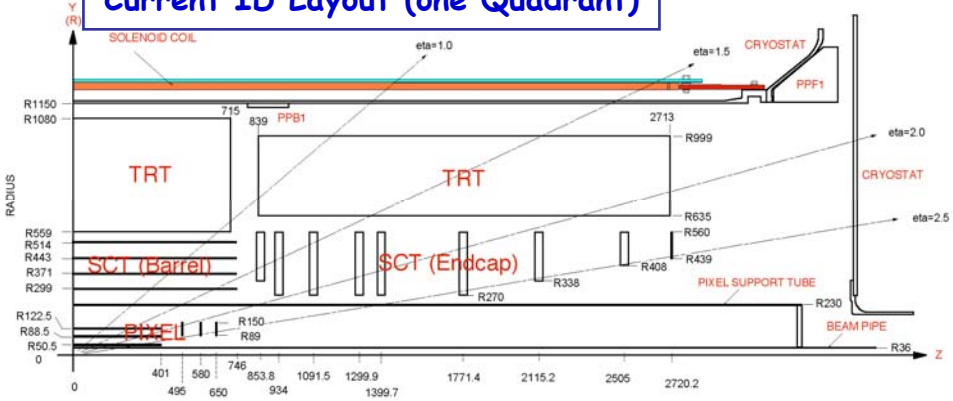
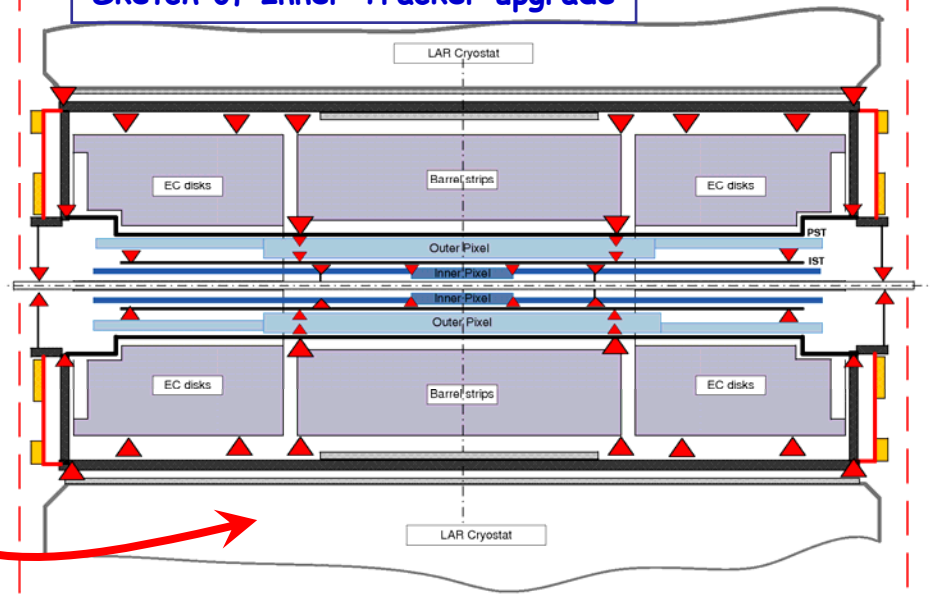
for ATLAS Inner Tracker Silicon Strip Upgrade Community

Silicon Strip Tracker Layout

Current ID Layout (one Quadrant)

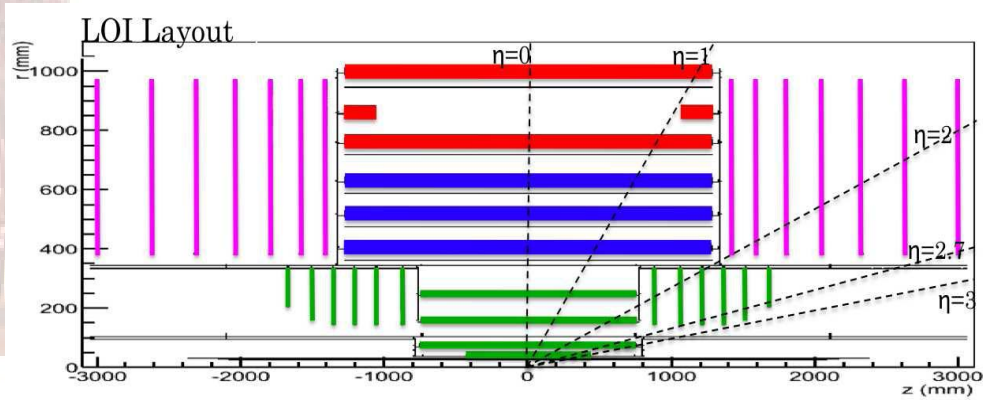


Sketch of Inner Tracker upgrade



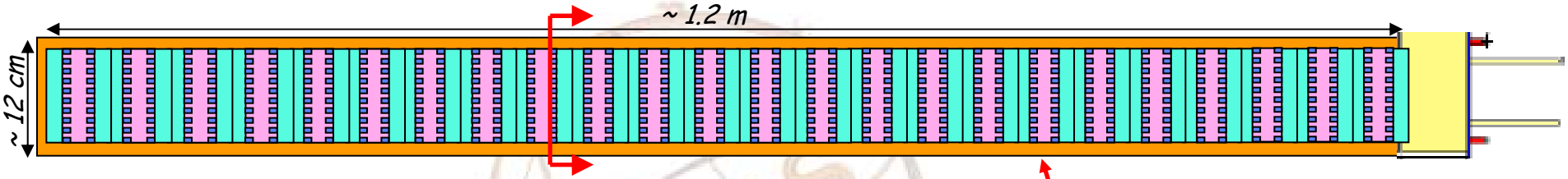
ATLAS HL-LHC Phase 2 Upgrade (~ 2022)
- All Silicon Inner Tracker
  Strips (replacing TRT + SCT) + Pixels
- More demanding in terms of:
  Occupancy, Radiation, Ch #, …

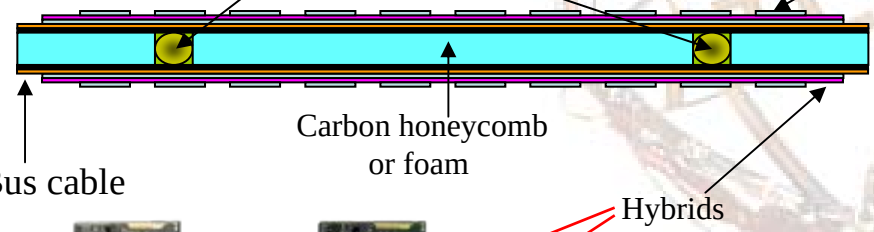
LoI Layout (Silicon Strip Tracker)
Barrel: 3 short + 2 Long + 1 Stub Layers
EndCaps: 7 Disks per End



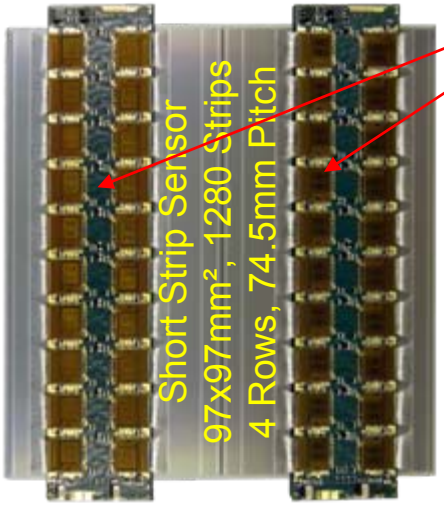
Barrel Staves I (Baseline Design)

Top view Stave w/ 12 Modules (ABCn 250nm r/o ASICs)

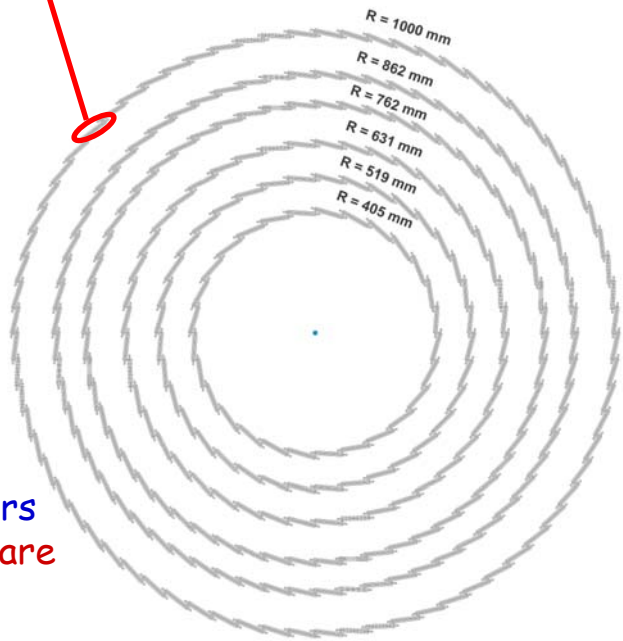




In total 472 Staves Installed
10° tilted on mechanical
Support structure



Built Physical Single sided Module

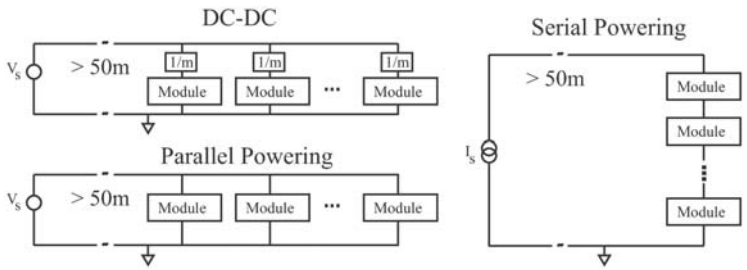


Barrel Baseline Concept: Stave
- Single sided modules mounted on highly integrated local support structures

Stave (single sided) Modules:
Hybrids glued directly on Barrel Strip sensors
Currently ~70 fully functional such modules are being built in various sites/institutes

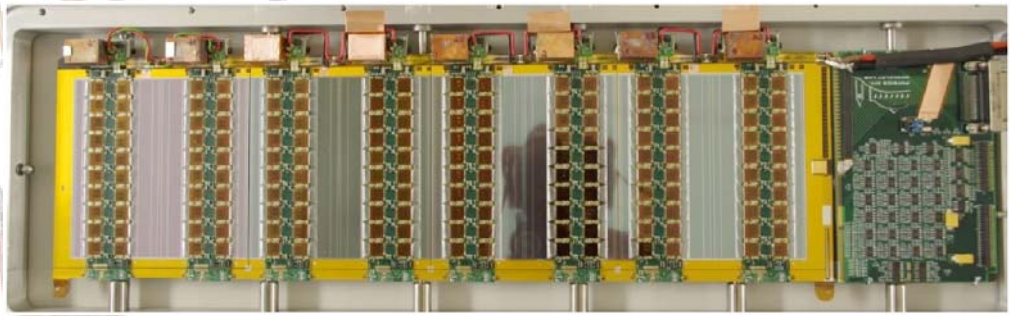
Barrel (ABCN-25) Stave Modules & Stavelet Serially/DC-DC Powering

Stavelet: shorter version of Stave. Consists of 4 modules
Barrel community actively tests various powering options, serial (SP) and DC-DC: so far no preferences
Two Prototype Stavelets are constructed for these studies (apart From special Lab setups)

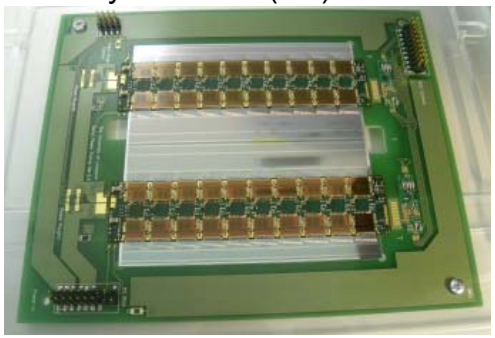


Stave Module (ABCN-25) Hybrid DC-DC Powered Test Frame

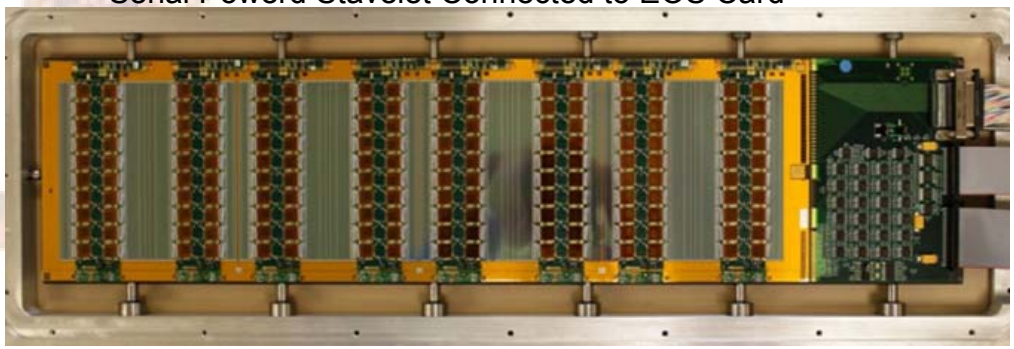
DC-DC Powerd Stavelet Connected to EOS Card



Stave Module (ABCN-25) Hybrid Serially Powered (SP) Test Frame



Serial Powerd Stavelet Connected to EOS Card



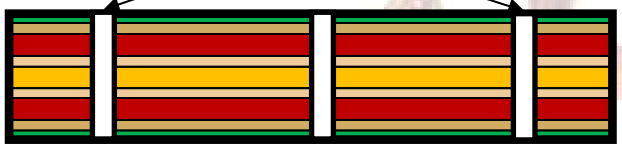
Barrel Hybrid (ABCn 250nm)

- Hybrid is designed to accommodate 20 x ABCN-25 readout ASICs (2 columns of 10)
- Layout topology matches large area sensor
- ASICs placed to match sensor pitch and bond pad profile
- Hybrid Power and Digital I/O bond fields at opposite ends
- Circuit exploits features of ABCN-25
  - Bi-directional data paths
  - Embedded distributed shunt regulators (for serial powering)
    - Requires external control circuit

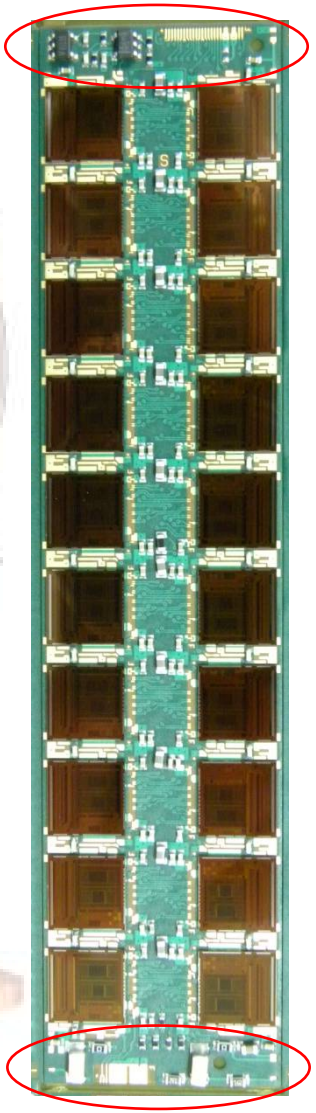
4 layer flex using conservative design rules
+ maintains optimum volume/yield100µm track/gap
blind vias (**375µm lands with 150µm drill)** 50µm dielectrics

Layer 1 & 2:	Signal
Layer3:	Analogue and Digital Power
Layer4:	Common Ground

Solder Resist (25µm)
5µm Cu foil carrier + Ni/Au plating (5µm)
Bond ply (50µm)
Cu (18µm)
Kapton (50µm)



Build thickness is ~280µm



Mshunt control and Digital I/O

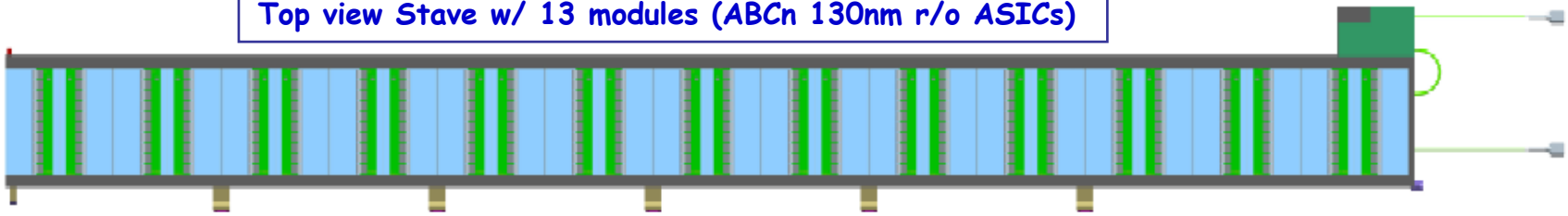
Tested successfully for functional and electrical performance

Input noise ≤400e ENC
Gain ~110mV/fC
Threshold variation ~1mV

Hybrid Power and sensor HV filtering (spec'd to 500V)

Barrel Staves II (Baseline Design)

Top view Stave w/ 13 modules (ABCn 130nm r/o ASICs)

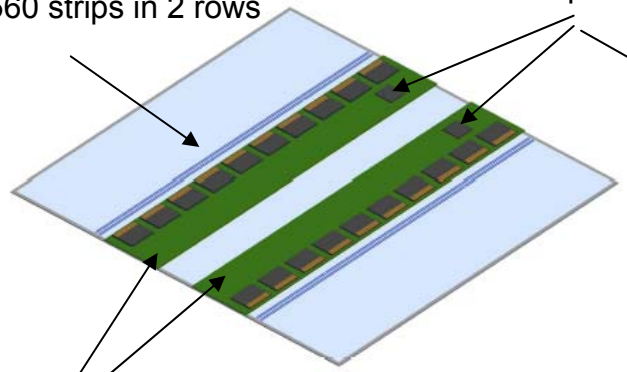


Barrel Silicon Strip Sensor
w/ 5120 strips in 4 rows
or 2560 strips in 2 rows

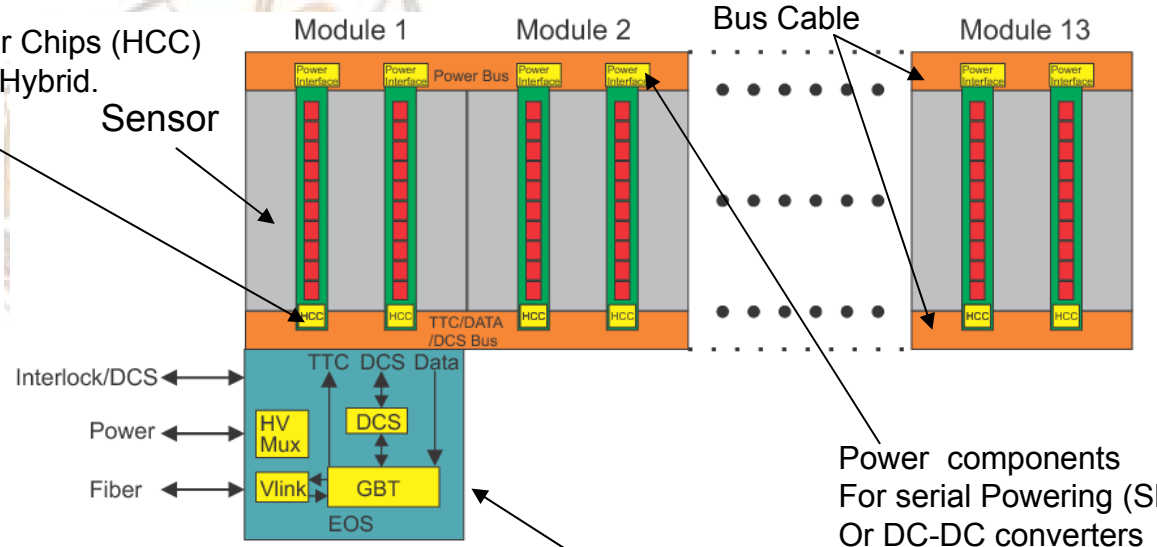
Hybrid Controller Chips (HCC)
One per Hybrid.

Sensor

Bus Cable



hybrids, each w/ 10 r/o ASICs (ABCN130)



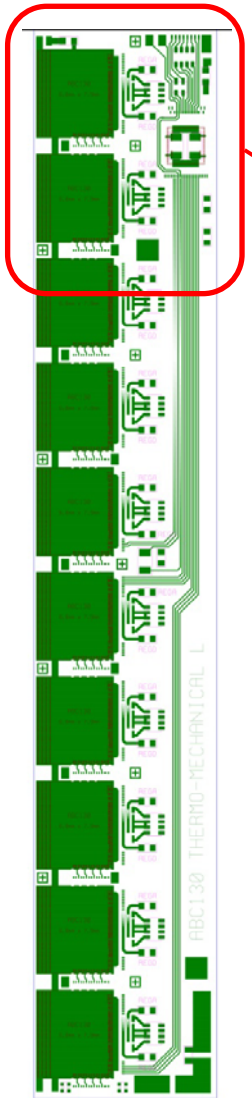
Power components
For serial Powering (SP)
Or DC-DC converters

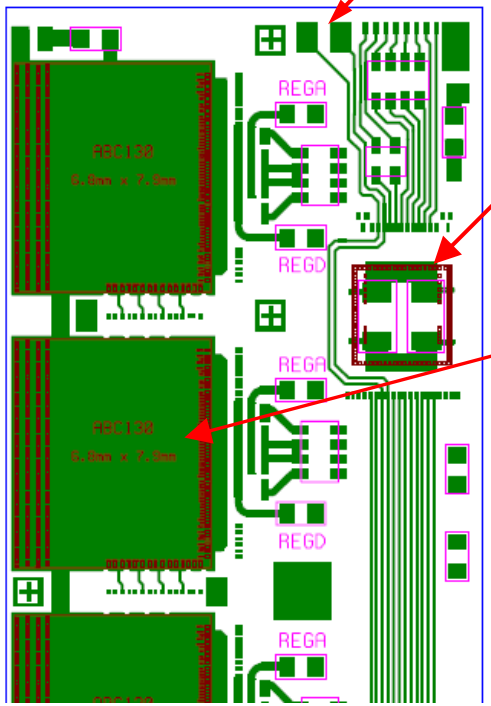
End of SubStructure (EOS) Card
Interfacing to off-Detector electronics

Stave (single sided) Modules:
Hybrids glued directly on Barrel Strip sensors

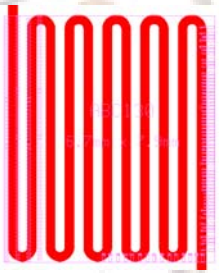
Barrel Baseline Concept: Stave (R/O,Power,etc.)
- Single sided modules mounted on Stave
- TTC/Data Through EoS, HCC to/from Hybrid

Barrel Hybrid (ABCn 130nm Thermo-Mechanical)



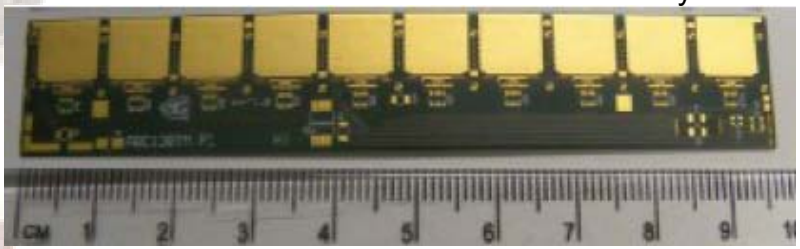


2 x 0.5Ω 1/4W for HCC heat load (0.25Ω total)



- 300µm x 18µm x 75mm trace geometry
  - Trace resistance/ABC130 ~225mΩ (~2.5Ω/hybrid)
- Expected Hybrid Power ~2W
  - 5W total/module (inc. Sensor contribution of 1W)
- 2.5V/1A across hybrid results in 5W/module
  - 65W/Stave side (65V/1A)

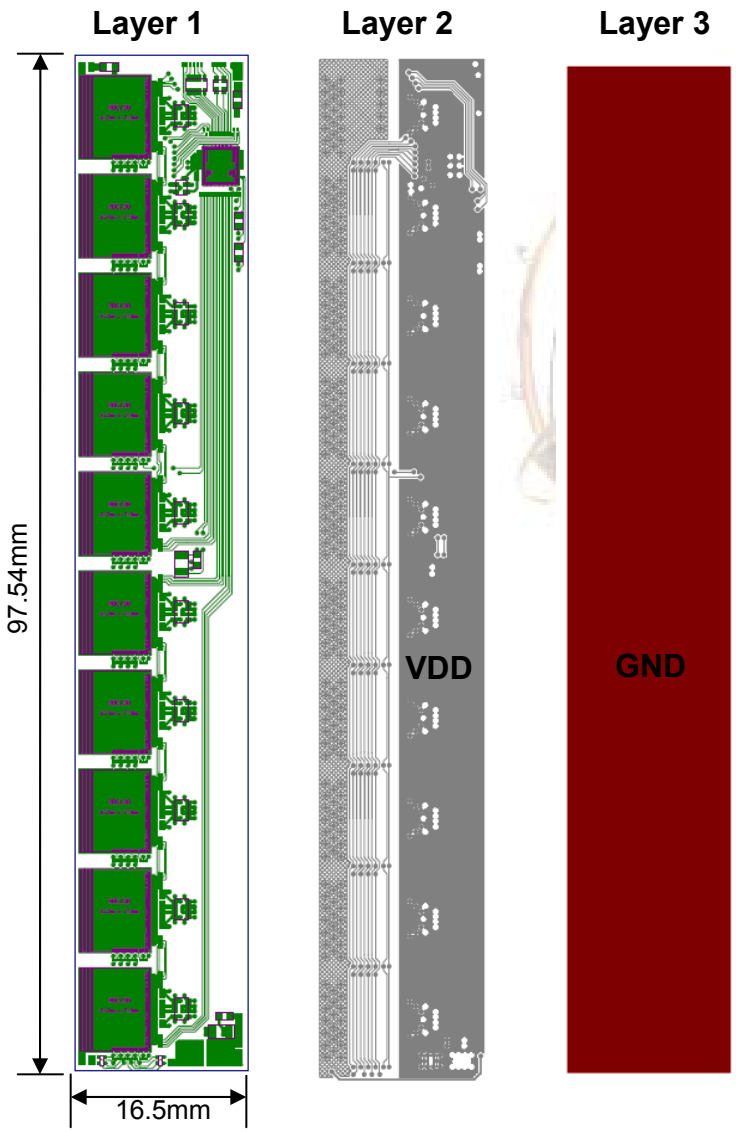
Manufactured Thermo-mechanical ABC130 Hybrid



- Build similar to electrical hybrid
- Identical Layer build-up, component footprints, tracks
  - w/ bond pad detail for evaluation
  - w/ SMDs to evaluate tooling (e.g. component clashes w/ wire-bonds)

- Resistive elements used to emulate asic heat load
  - 0805 resistors for HCC
  - Embedded trace for ABC130 - dummy asic placement possible to evaluate tooling etc.

Barrel Stave Hybrid (ABCn 130nm)



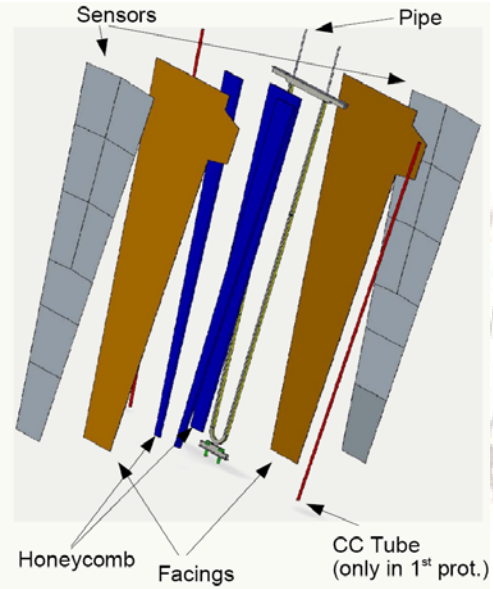
Hybrid Detail

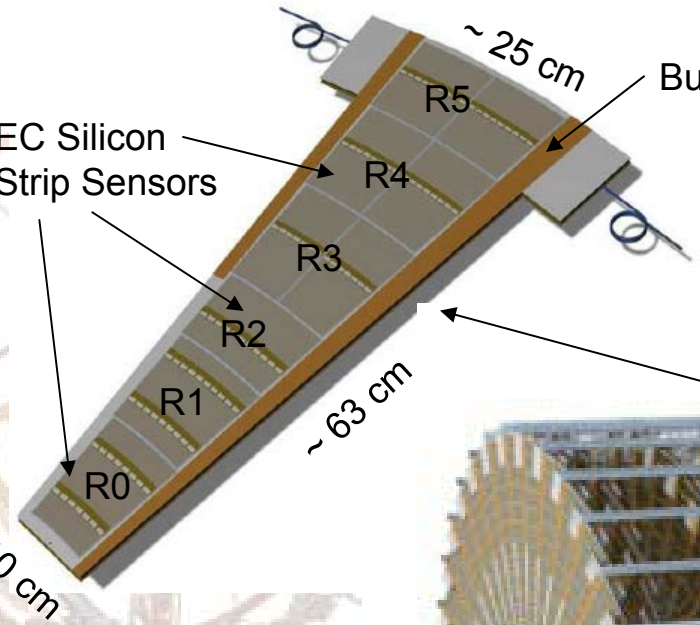
- 10x ABC130 + 1x HCC
  - Two data loops w/ 5xABC130 each
  - Redundant readout at each end of data loop
  - TTC bus runs under asics – allows removal of a layer
  - "Fast Cluster Finder" Signalling not routed on this hybrid
    - Will appear on another dedicated version
- Hybrid: 16.5mm x 97.54mm
  - ~ 40% reduction in area w.r.t. ABCN-25 hybrid
  - Geometry adapted to Sensor size – no overhang
- 3 layer Kapton flex
  - Thin build using 50µm Kapton dielectrics with 18µm Cu
  - Typically ≥100µm track & gap with 150µm drilled blind vias
  - Layer 1: Component + trace
  - Layer 2: Trace + VDD + hatched GND (for balanced build)
  - Layer 3: GND
- Power protection/control and HV filtering moved off hybrid
  - Attached to the Bus cable
  - Ensures non-overhanging hybrid

Will come in 2 flavours "Left-handed and Right-handed"

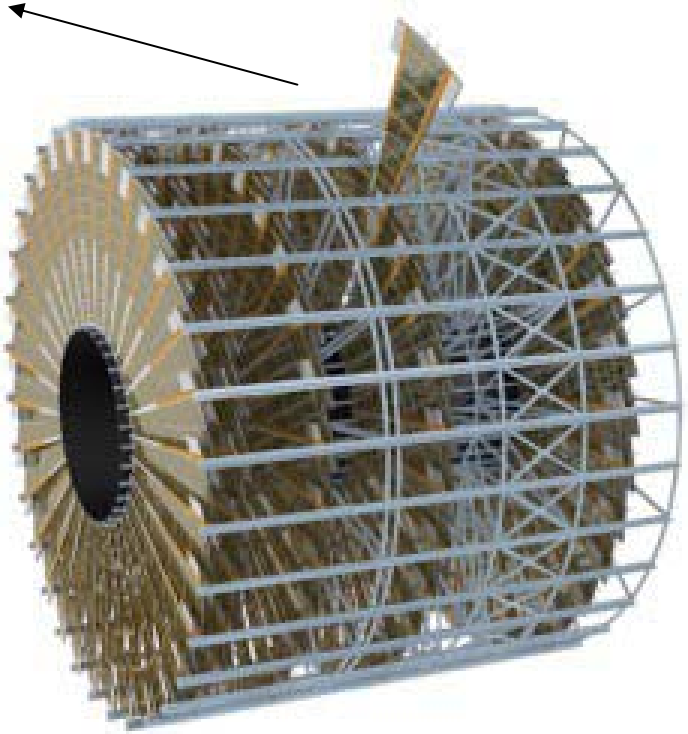
EndCap Petal (Baseline Design)

Exploded view of a Petal w/ sensors on both sides





32 Petals per disk
446 petals in total

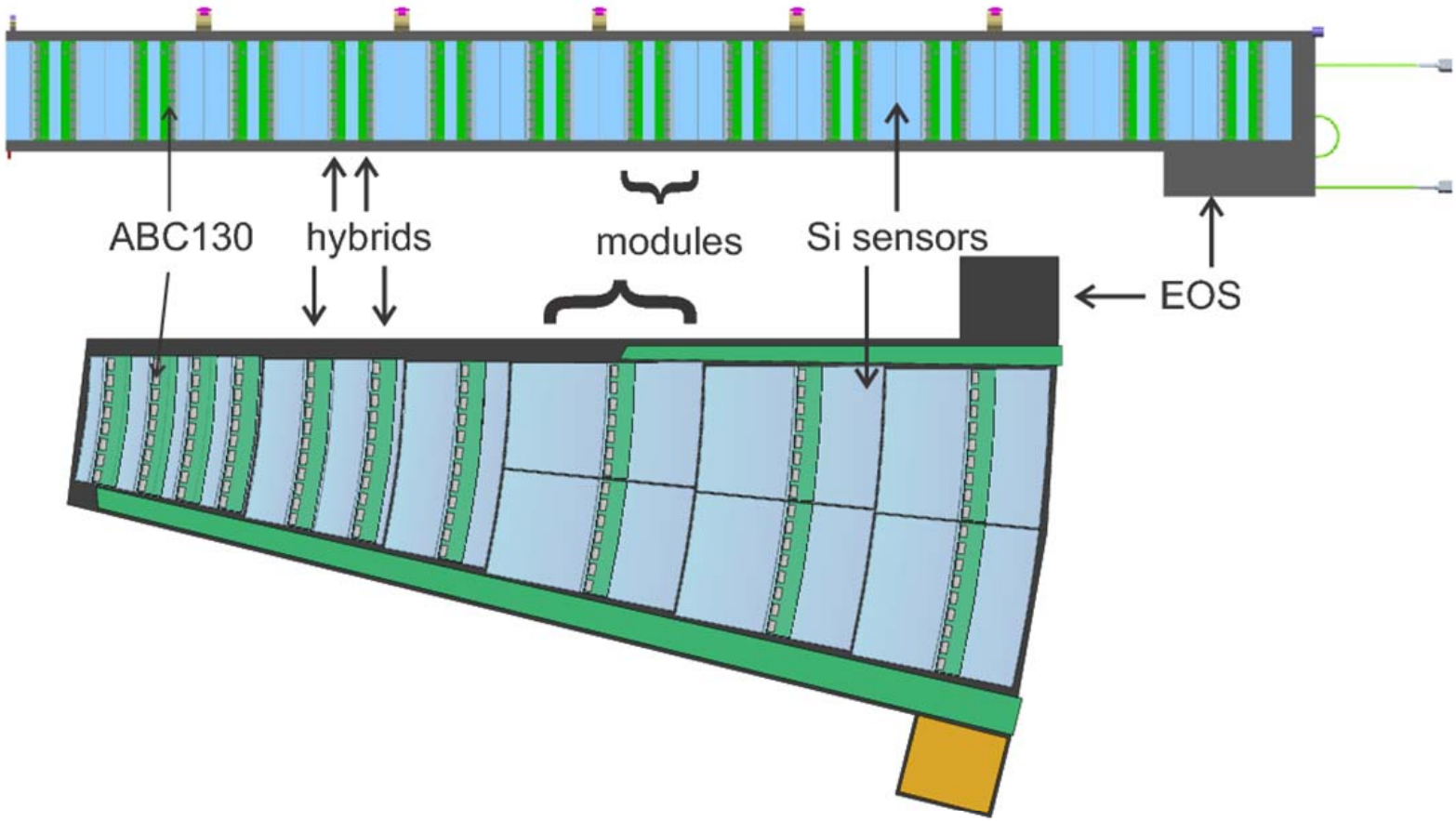


Sketch of one EndCap w/ support Structure and some installed petals/disks

EndCap Baseline Concept (following closely that of Stave)
- Each EC disk subdivided in Wedge shaped Petals
- Each disk/Petal subdivided in Rings (R0-R5)
- Single sided modules mounted on Petal
- Different Sensors/Ring
  -> up to 9 different Hybrids w/ varying r/o ASIC counts
- ASIC I/O Wire bonding to Sensor demanding on inner Rings
- Split Sensor Layout on upper rings -> complicate Hybrid design

Petal (single sided) Modules:
Hybrids glued directly on EC Strip sensors

Barrel/EndCap Single Sided Modules (comparison)



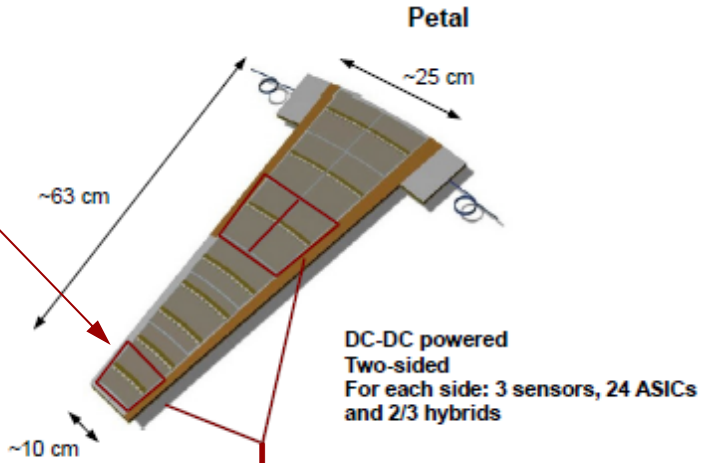
EndCap Petalet (the aim)

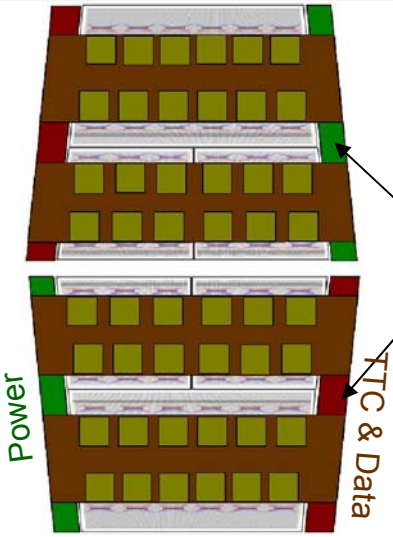
Petalet (a mini Petal single sided modules on either side) Project:
- gain experience w/ module assembly
- study Hybrid design, e.g. for fine strip-pitch inner ring sensors

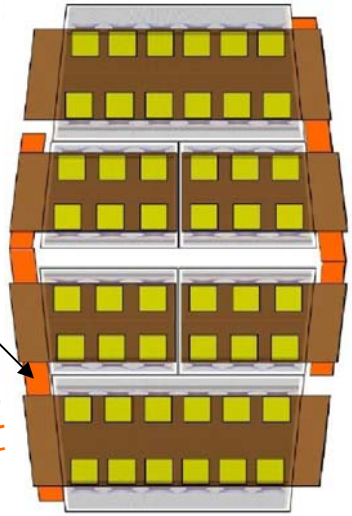
Two variants

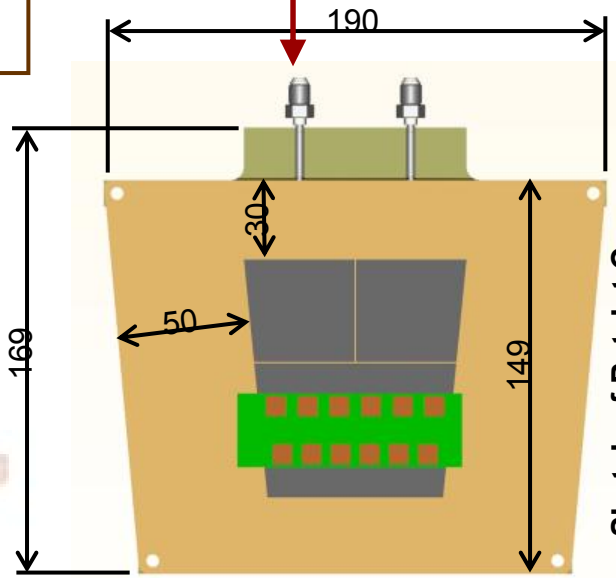
The Bear (below left)
- Split Power / TTC+Data Bus Tapes
- Hybrid for upper mini sensors spans across both sensors
- 2 rows of each 6 ABCn-25 ASICs on each Hybrid

Lamb & Flag (below right)
- TTX & Data + Power on the same Bus Tape
- Separate Hybrids for upper mini sensors
  - Each w/ 2 rows of 3x ABCn-25 ASICs
- Single Lower Hybrid w/ w/ 2 rows of 6x ABCn-25 ASICs





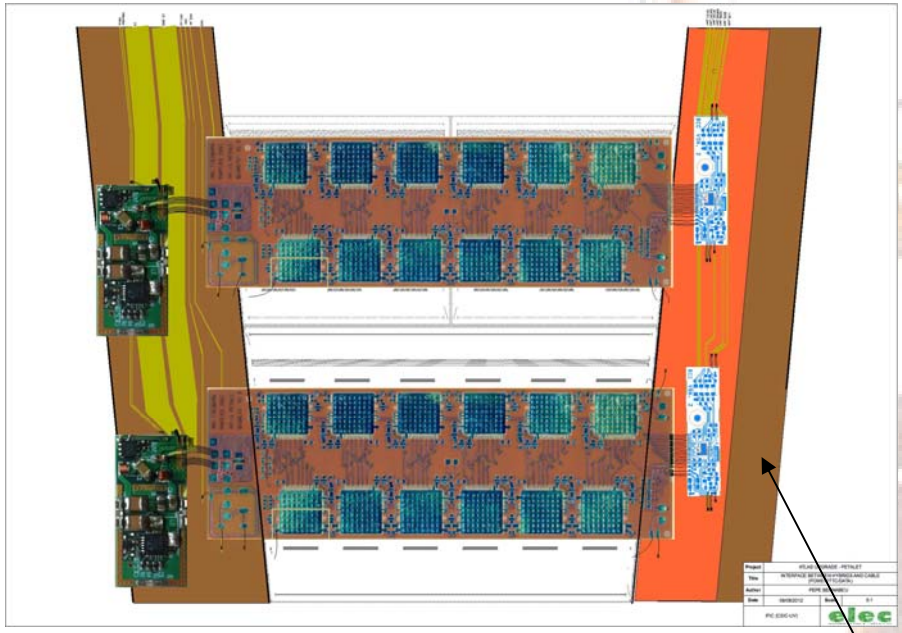




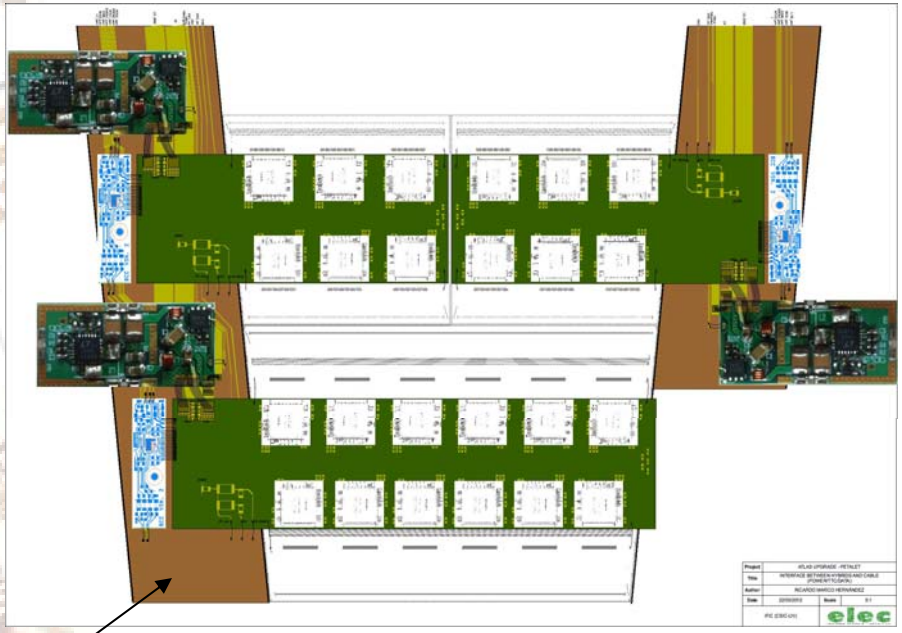
Sketch of Petalet Core indicating cooling pipe and sensors position

EndCap Petalet Flavours

"The Bear"



"Lamb & Flag"



Bus Tape

Sketch of electrical Petalet showing relative positions of Bus-Tape, Sensors, Hybrids, BCC-brd, DC-DC board for "the Bear" and "Lamb & Flag" Options

"The Bear" Petalet Hybrids' Specs

4 Layer Flex Kapton PCB (standard design rules)

- brownish coverlay Soldermask Top
- L1 (top layer) Component Side
- L2 (1st inner Layer) Power plane (VDD)
- L3 (2nd inner Layer) Signal (differential)
- L4 (bottom Layer) Power plane (GND)
- brownish coverlay Soldermask Bottom

Hybrid Build:

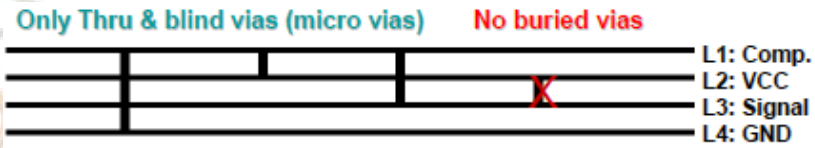
-Soldermask (Top & Bottom):
Photosensitive dry film Coverlay
-Adhesiveless single/double sided ED Copper-Clad
-> all-Polyimide Laminate
-Sheet Adhesive: Acrylic
-Surface finish:
Electroless Nickel Immersion Gold (ENIG)

Design Rules:

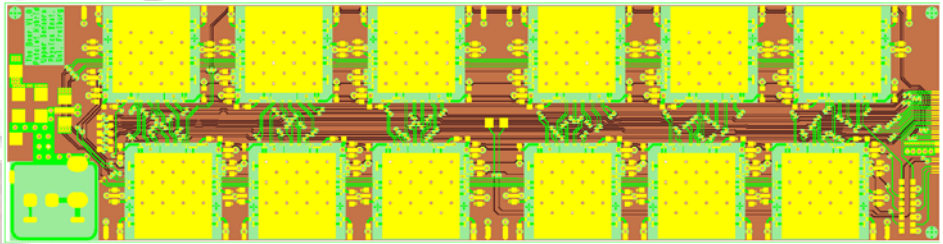
Track width/gap 100µ/100µ
Micro-via: Drill/Pad
100/300µ (L1/-2) 125/350µ (L1-3), 250/500µ (L1-4)

Assembly/wire-bonding in house:
Automatic pick & place, reflow soldering
wire-bonding (25µm Al)

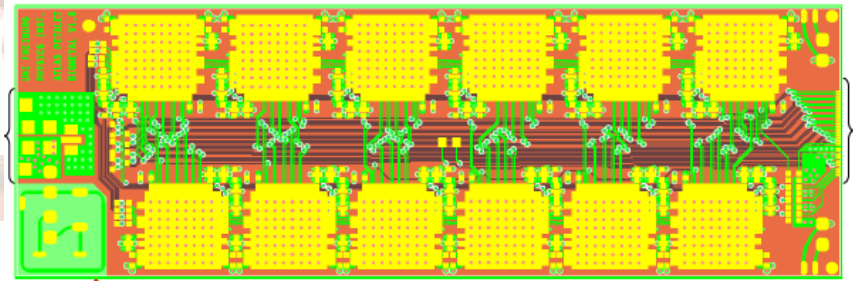
Layer stack-up



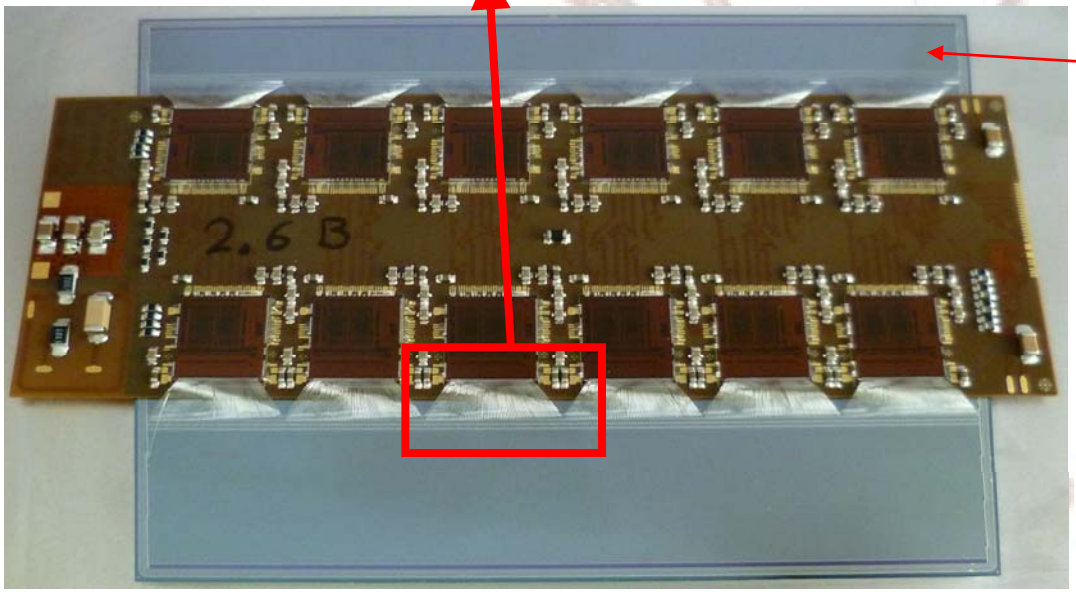
Upper hybrid (92 mm x 23.5 mm)

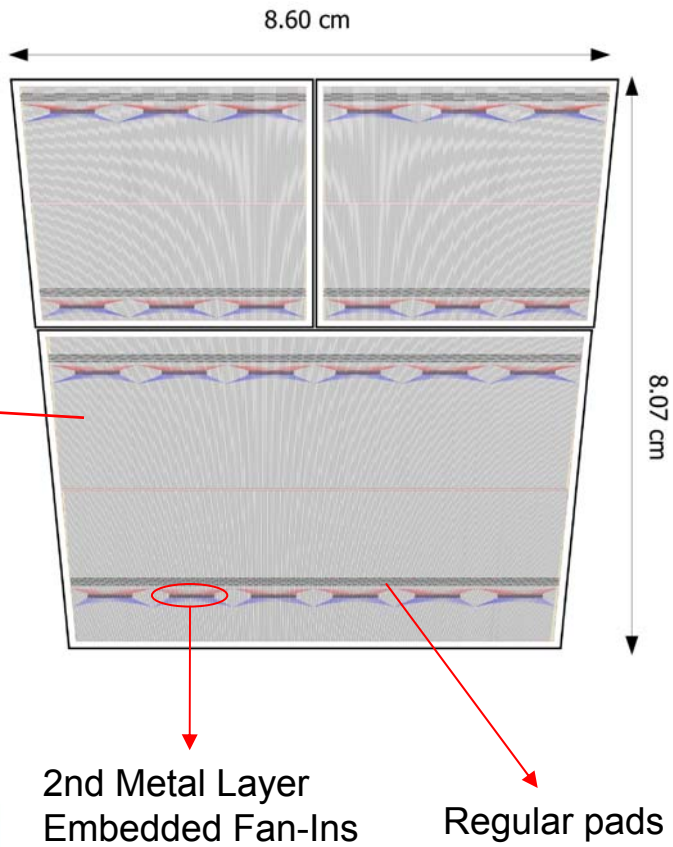


Lower hybrid (85 mm x 28 mm)



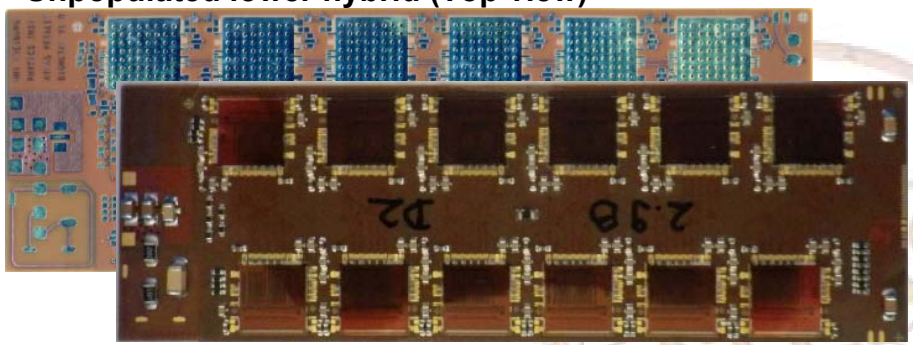
Wire-Bonding to EndCap sensors (large angles)





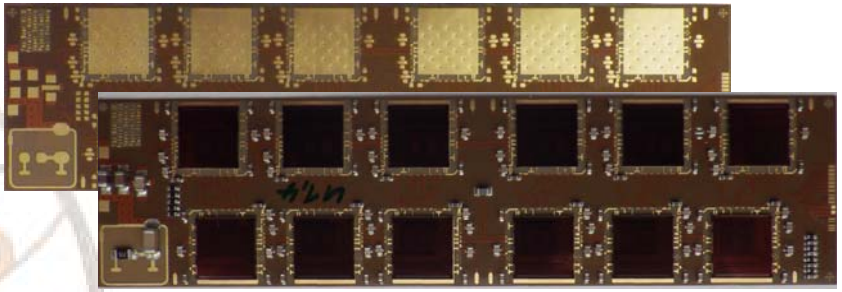
"The Bear" Petalet Hybrids (Assembly, Test, …)

Unpopulated lower hybrid (Top view)



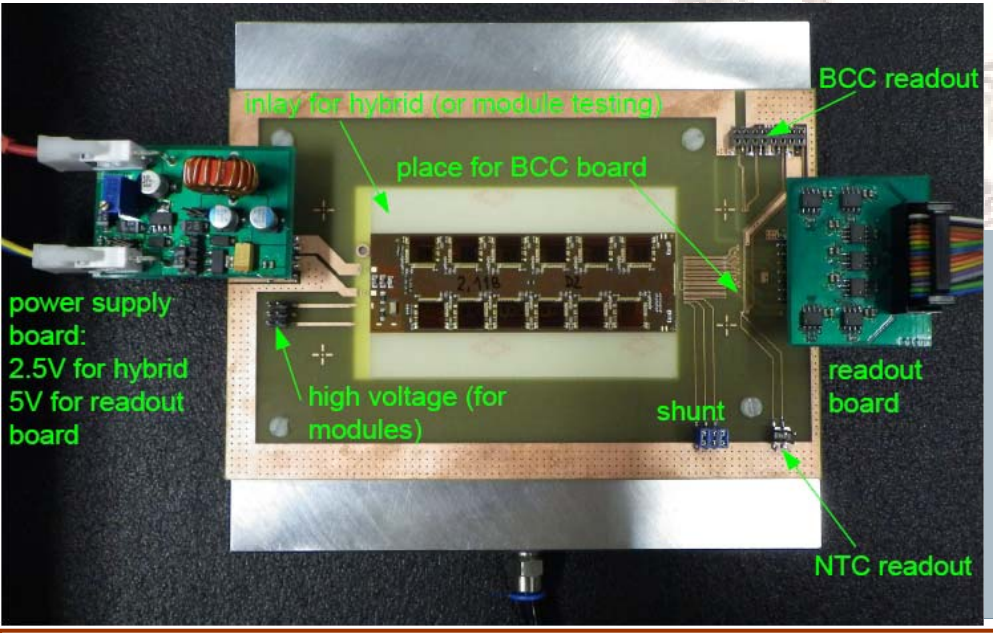
Fully assmbled lower hybrid (SMDs/ASICs)

Unpopulated upper hybrid (Top view)

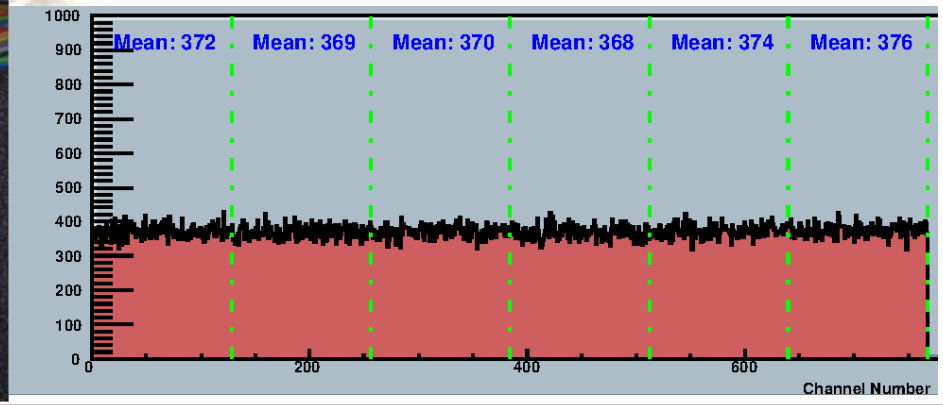


Fully assmbled upper hybrid (SMDs/ASICs)

- Single Hybrid Electrical tests
  - Seen in Fig. lower left: Test frame mounted on Test jig (w/ Cooling) and daughter boards (Power and LVDS buffers)
- hybrid tests show good performance: ~ 380 ENC



Typical measured Input noise (<400e) vs Ch#



"Lamb&Flag" Petalet Hybrids Specs

4 Layer flex PCB:

- SIGNAL 1 dedicated to components and signals.
- SIGNAL 2 dedicated to LVDS and CMOS signals(microstrip).
- POWER for hybrid power plane VDD.
- GND for hybrid ground plane (common GND).

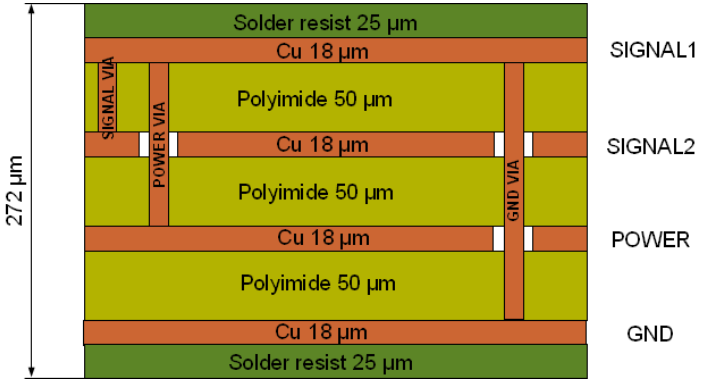
PCB characteristics:

- Flexible photosensitive soldermask (top/bottom).
- Adhesiveless single/double sided ED copper-clad all-polymide laminate (AP7163E/AP7156 from DuPont).
- Acrylic sheet adhesive (LF0100 from DuPont).
- Surface finish: Electroless Nickel Inmersion Gold (Ni/Au).

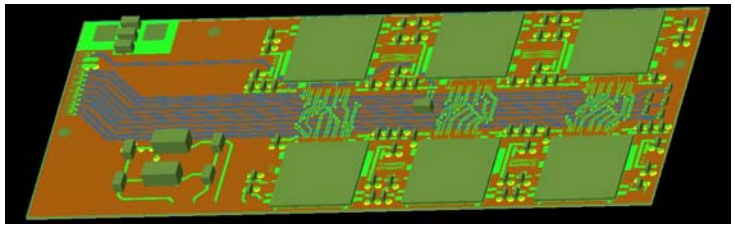
Design Rules:

- Track and gap of 100 µm.
- GND_VIA (through-hole): 80/400/700 µm diameter/land/clearance.
- POWER_VIA (blind via): 80/400/700 µm diameter/land/clearance.
- SIGNAL_VIA (blind via): 80/300/600 µm diameter/land/clearance.

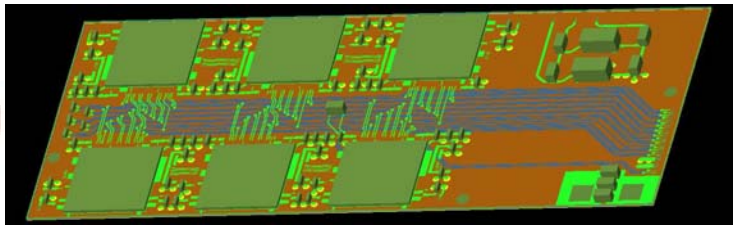
Hybrid cross section



Upper Left hybrid (24 mm x 57.580 mm)



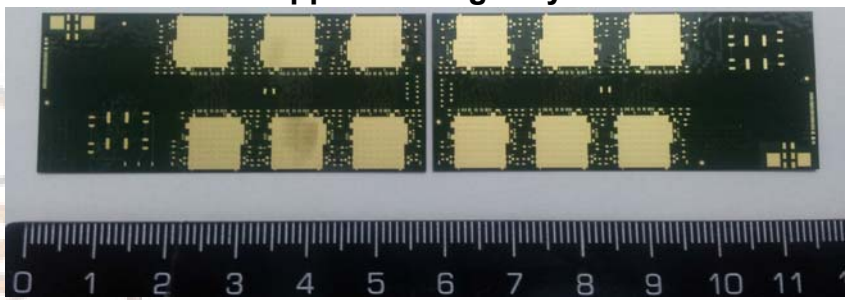
Upper Right hybrid (24 mm x 57.580 mm)



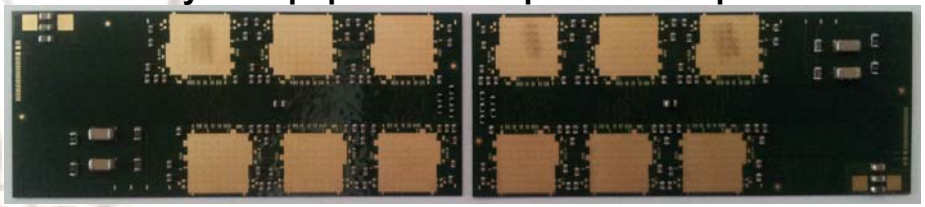
"Lamb&Flag" Petalet Hybrids: Assembly, Test, …

- First production batch done
- Population with passive components (external)
- Mounting ASICs on hybrids w/ an in house flip-chip machine
- Jig for hybrid wire-bonding and hybrid electrical tests (production ongoing in-house)

Upper Left/Right hybrids

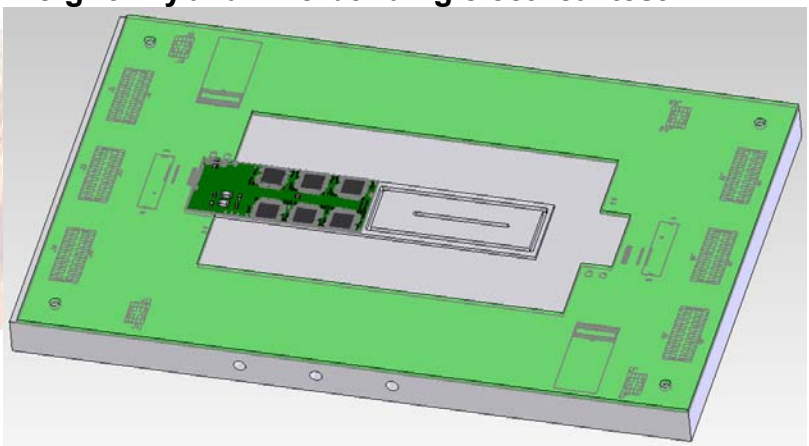


UL/R hybrids populated with passive components



Flip-chip machine

Jig for hybrid wire-bonding/electrical test



Final Remarks

Preparations for the ATLAS Silicon Strip Inner Tracker Upgrade is well underway, Detector Layout to a large extent defined (LoI Layout) to allow explore different implementation options (R&D)

Prototypes of several electrical/mechanical components/subsystems are being Produced and tested
Alternative approaches are being exploited, while keeping in mind the overall material budget and cost

In terms of SubSystems (Barrel/EndCap)

Stave: Prototype phase quite mature, Stave module building under control, Stavelet construction and tests specially in terms of SP or DC-DC Powering schemes quite evolved and still ongoing. Hybrid: successful design and manufacturing of various flavours (for ABCn-25 and recently thermo-mechanical for ABC130 r/o ASICs) w/ excellent test results, successful panelisation attempt to allow mass assembly (preparation for production phase and industrialization).

Petal: A baseline EndCap Strip Sensor and Petal Layout does exist. Benefiting from experiences and inputs from Barrel Stave Program, first small scale prototyping (Petalet) is ongoing. Here different design options will be exploited to adopt the best option for Petal module Design. A prototype Bus Tape for the Petalet project is also designed and will be submitted soon. EndCap sticks for the time being to DC-DC Powering scheme.

Next Steps: The ABC130 ASIC will soon be available -> first Barrel ABC130 Hybrid is designed and soon will be tested. Based on it's outcome & Petalet Studies, corresponding Hybrids for the Petal will be designed. Full utilization of the functionalities in ABC130 puts tight constraints on Hybrid design. Specially demanding for inner ring sensors of the EndCap strip sensors w/ very short and fine pitched strips.

Hybrid manufacturing in industry, Assembly & Module building are performed in-house with automatic machines (e.g. pick&place, Wire bonder, Flip-Chip Bonder) along w/ specially designed/produced Toolings.