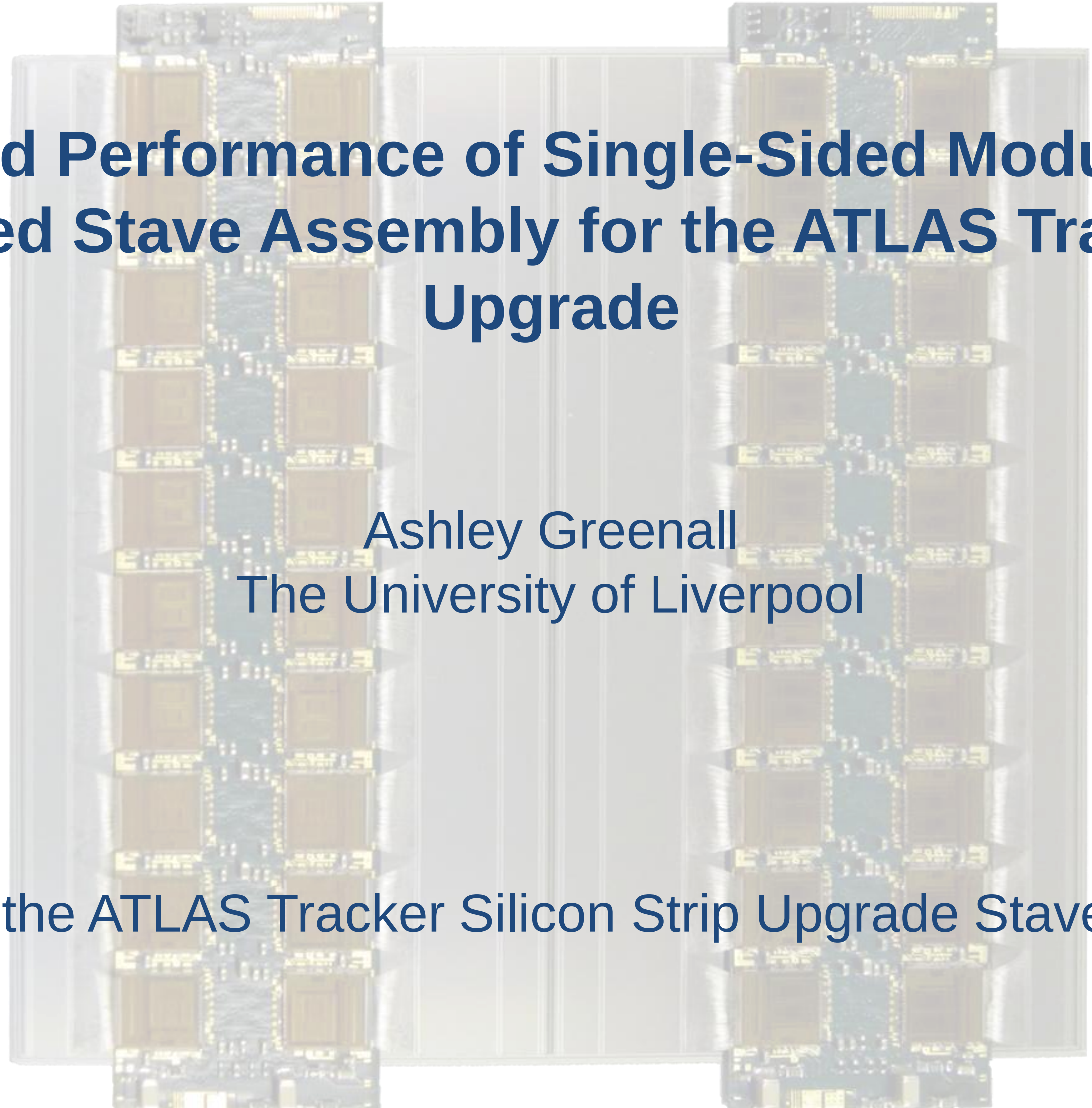
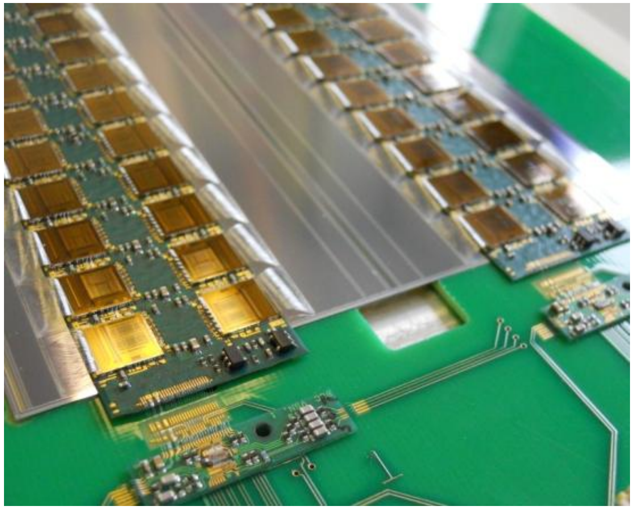


Design and Performance of Single-Sided Modules within an Integrated Stave Assembly for the ATLAS Tracker Barrel Upgrade

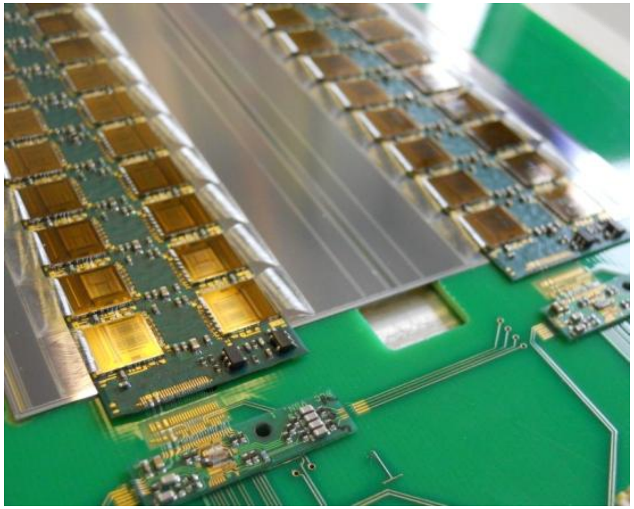
Ashley Greenall
The University of Liverpool

On behalf of the ATLAS Tracker Silicon Strip Upgrade Stave Programme

Outline



- **Introduction to the Stave concept**
- **Stave flex hybrid**
  - **Assembly & Electrical performance**
- **Stave module**
  - **Assembly & Electrical performance**
  - **First look at multi-module performance**
- **Summary and outlook**



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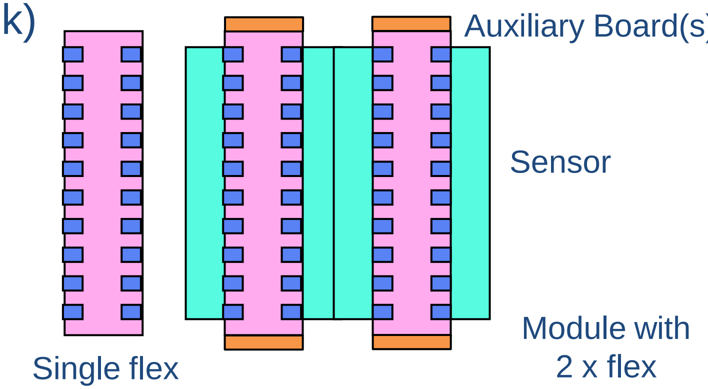
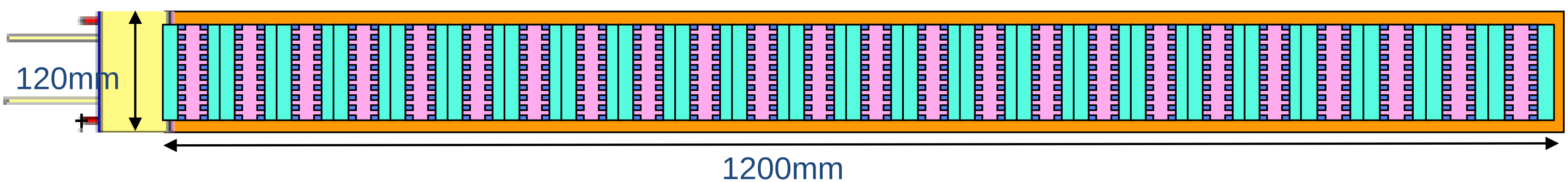
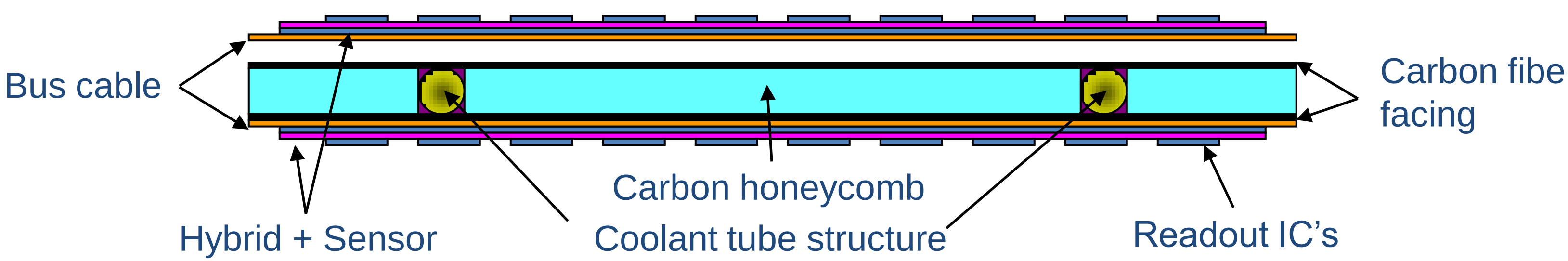
Stave – Geometry and components

- P-type 4 segment crystals (10cmx10cm , 320µm thick)
  - 4 blocks of 1280 strips, 5120 total
- ABCN-25 readout ASIC
  - 40 per module
  - 960 per stave (>120k channels)
- Kapton flex hybrid with auxiliary boards
  - BCC ASIC (multi drop & point-to-point I/O)
  - Serial Power protection
- Serial powering of modules
- Embedded Kapton bus cable
  - End of stave card
- Stave mechanical core

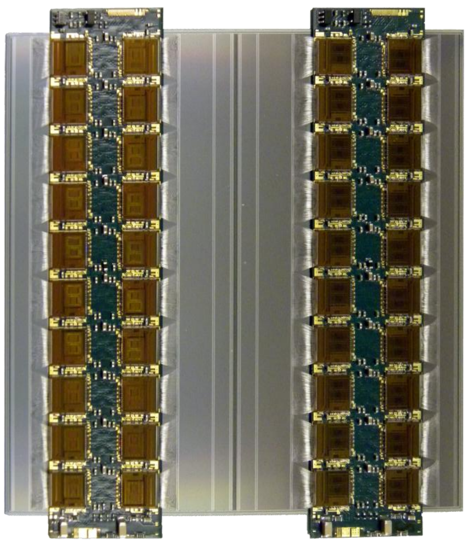






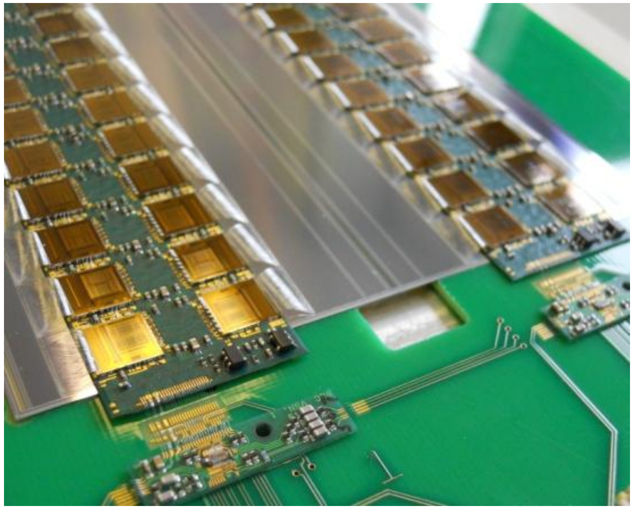
Stave Module Requirements

Design is driven by minimising material



- Hybrid is substrate-less and with no connectors
  - Glued directly on to the sensor
    - Provides mechanical support and thermal management
  - All off-module connections made via wire bonds
- Use of minimal glue layers for both ASIC and hybrid attachment
  - Improves thermal paths and again reduces material
- Pitch adapters not used, direct ASIC-to-Sensor wire bonding
  - Constrains relative placement w.r.t. sensor to better than 80µm
- Layout optimised for Stave and Serial powering (parallel optional)
  - Scalable serial power connection (for multiple modules)
  - 2.5V offset between hybrids (5V across a single module)

- Opportunity to look at mass production methods (future build will require >10000 circuits)
  - Yield and reliability of flex circuits taken into account from the beginning
  - Mass wire bonding, component attachment and testing of circuits
  - Possible to implement techniques with minimum financial penalty (capital outlay etc.)?



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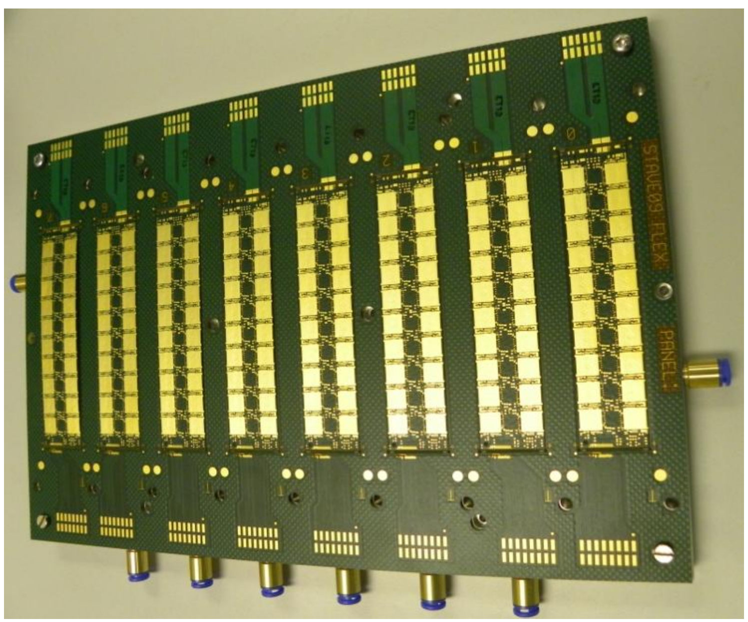
Stave flex hybrid – Design for manufacture

- 5 layer flex using conservative design rules – maintains optimum volume/yield
  - 100µm track and gap, blind vias (**375µm lands with 150µm drill)** and 50µm dielectrics
  - Non-esoteric design – relatively cheap to produce

- First pass at industrialisation of hybrids
  - Panelisation of flexes – allows mass wire-bonding and testing of circuits
  - Design for machine placement and solder re-flow of passive components
  - Mass attachment of bare die



- Panel is composed of 8 'active' circuits
  - Flexi-rigid build
  - 5 layer flex selectively laminated to FR4
    - Flex is 4 active layers + shield (asymmetric stack up)
  - FR4 acts as temporary substrate during assembly

- Panel dimension is 300mm x 200mm
  - Geometry determined by pick-n-place machine

- Flex active circuit is 24mm x 107.6mm
  - It is this which is detached from the panel

- Completed circuits are electrically tested on the panel
  - After component attachment and wire bonding

- **Vendors yield, of panel, is >96%**

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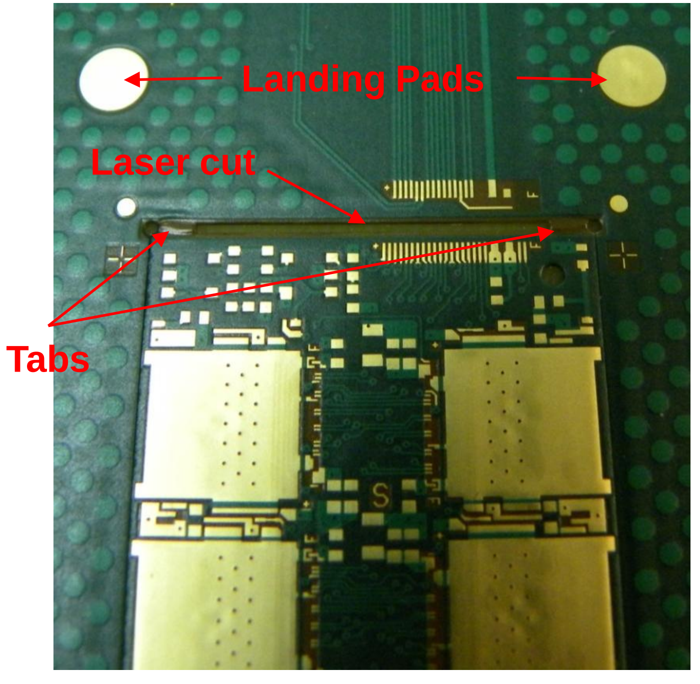
Panel Details

- Lamination of Kapton flex to FR4 incurs shrinkage
  - Typically 1.5mm over 300m and 0.5mm over 200mm (x and y respectively)
    - Machine placement of passives difficult and incurs solder stencil misalignment
    - Complication of some panel tooling holes having to track shrinkage – challenging for vendor

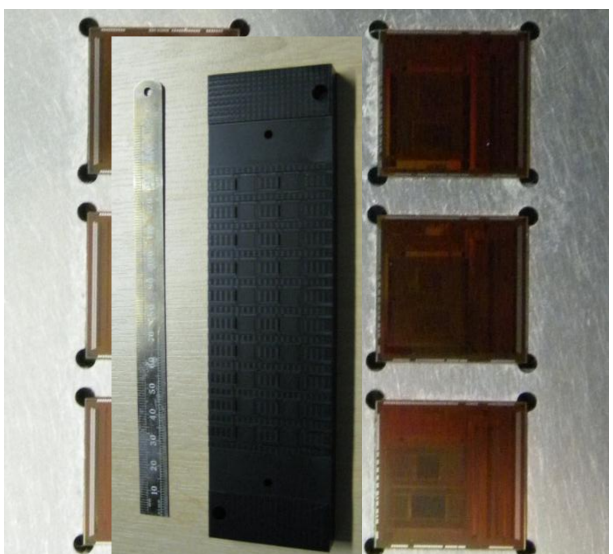
- Requires a 2nd run with shrinkage correction input at CAM stage
  - **Shrinkage now well controlled at ≤50μm for both x and y**

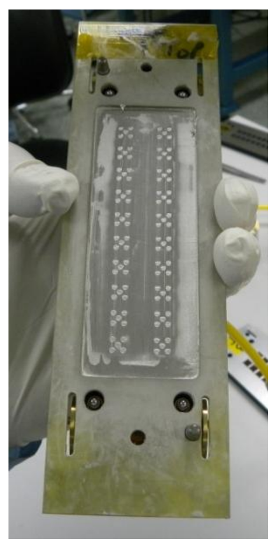


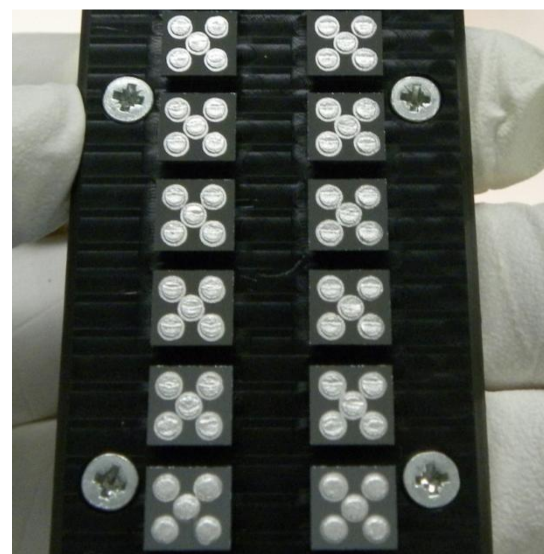
- Circuits are laser cut on 4 sides
- 4 tabs, 1 per corner, used to retain circuit(s)
  - No bond ply beneath circuit
- Use non-flexible solder resist (25μm thickness)
  - Improved registration (compared to flexible resist)
  - Adds rigidity to circuit
- Cu dot hatch added by vendor
  - Makes lamination of flex to FR4 more uniform (& plating)
  - BUT dots are ~40μm high w.r.t. Kapton carrier
  - Introduces non-uniformity in glue layer when attaching die (aim for ~80μm glue thickness)
  - Solution was to add 'landing pads' for chip placement and hybrid pick up tool (**Flatness of landing pads w.r.t. ASIC sites is ~10μm**)

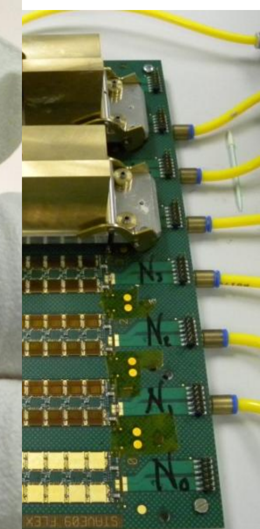
ASIC 'Mass' Attachment

- Attach 20 x ASICs to a single hybrid (on a panel) at a time, using conductive glue
  - Important to control chip-to-chip alignment to better than 80µm and maintain their planarity to 10µm
  - Constraint on planarity necessary as we pick up the completed hybrid via the chip faces when gluing to the sensor - at this stage the hybrid will be 'flexible' (due to having no substrate) and is wire bonded.
- Make use of a 'chip-tray' (pre-load with ASICs) - geometry matches that of the ASIC sites on the hybrid
  - Made from Acetal (Static Dissipative), with a 125µm thick laser cut stencil added for precision alignment of ASICs
- All ASICs picked up in one step from the tray using a vacuum pickup tool and then have glue applied
  - Again using a 125µm thick stencil (cut to match glue profile) and ensure uniform glue thickness applied
- Then ready to attach all 20 x ASICs in one go to the flex







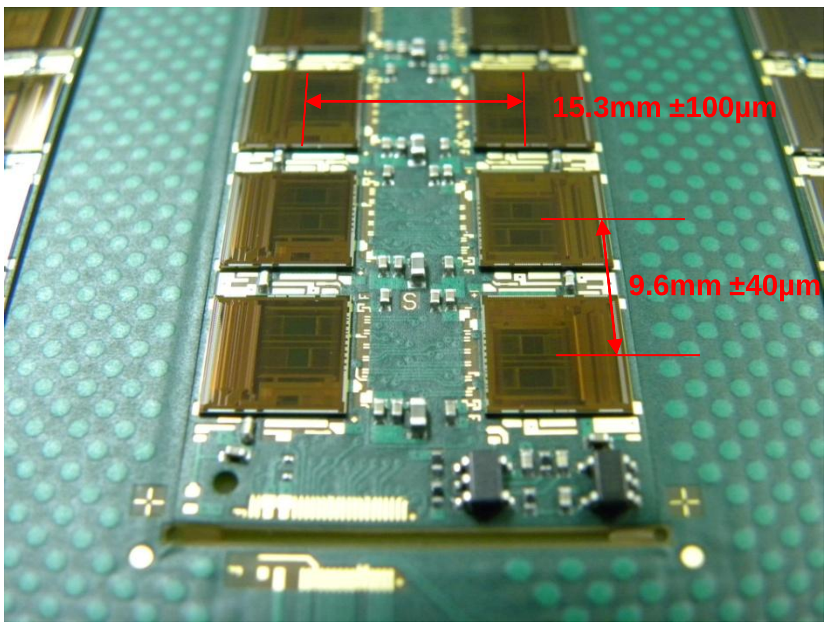


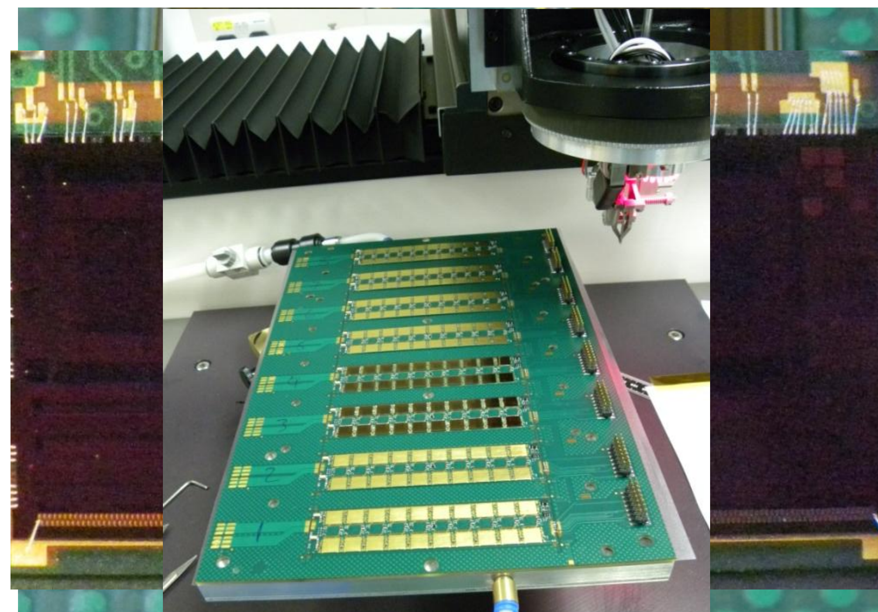
Component Attachment and wire bonding – Finished item

- Pick-n-place and reflow of passives on a panel is straightforward (as a normal FR4 circuit)

- Chip-to-chip placement (within a column) is <15µm RMS of requirement
  - Column-to-column placement is <20µm RMS
- Glue thickness is very uniform with chip planarity <10µm
  - No evidence of wicking of glue from undersides of ASICs

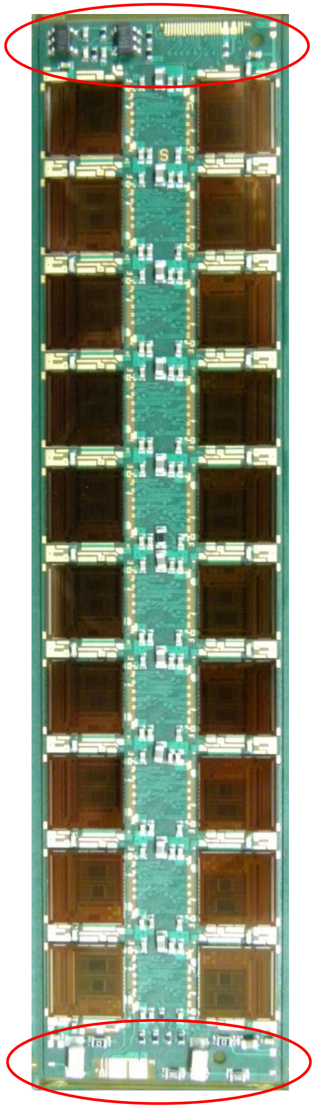
- No problems with wire-bonding of ASICs on flexes – vacuumed down during this stage
  - Hesse & Knipps Bondjet BJ710 & BJ820 (10 minutes/flex for 20 ASICs on the 820)





Stave Hybrid – Layout and Electrical Detail

- Hybrid is designed to accommodate 20 x ABCN-25 readout ASICs (2 columns of 10)
- Layout topology matches ATLAS07 large area sensor and serially powered Bus cable
  - 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



Mshunt control and Digital I/O

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

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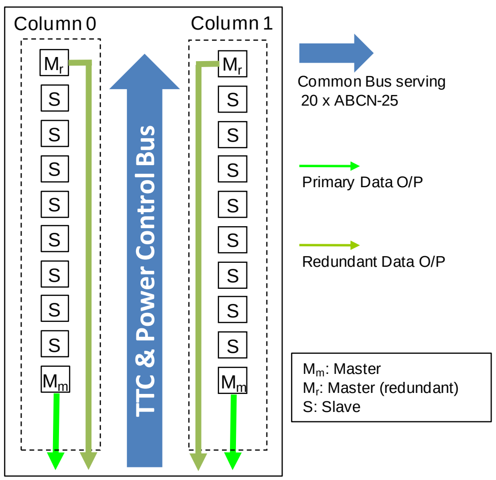
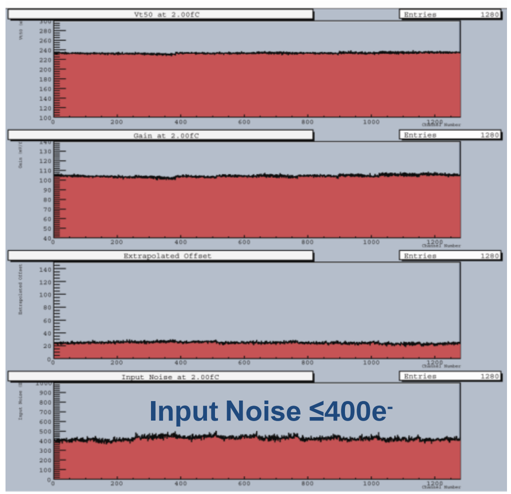
Stave Hybrid – Electrical Performance

- Hybrids are tested for functional and electrical performance whilst on the panel
  - Check that shunt regulators work
    - Can alternatively be powered in ‘traditional’ parallel mode (bench PSU or DCDC for example)
  - Testing of bi-directional data paths (4 data paths total per hybrid)
  - Input noise, Gain and threshold variation

Readout Topology

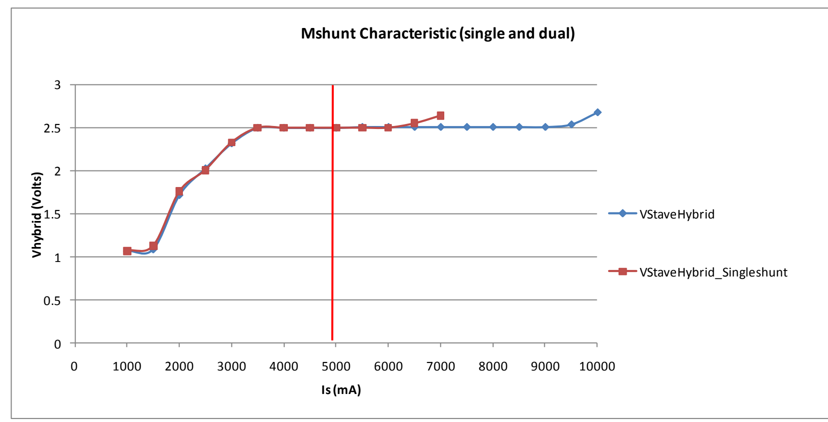


Characterisation of 10 x ABCN-25

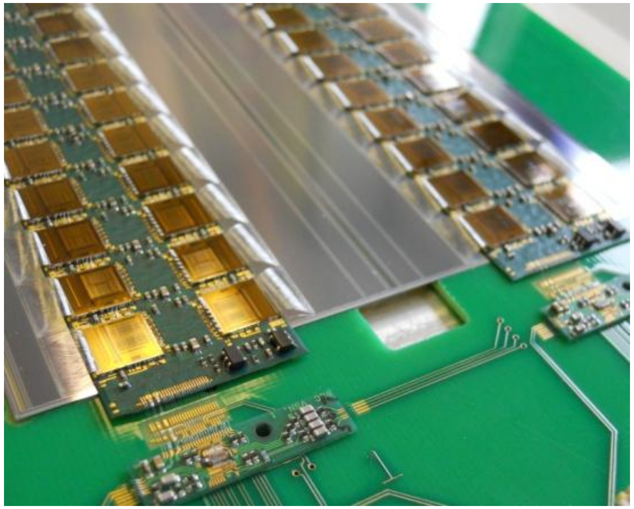


- Input noise ≤400e ENC
- Gain ~110mV/fC
- Threshold variation ~1mV

Shunt Regulation



Mshunt characteristic for single and dual shunts enabled per ABCN-25 on a 20 ASIC hybrid
(expect max. Hybrid shunted current to be ≤5A)



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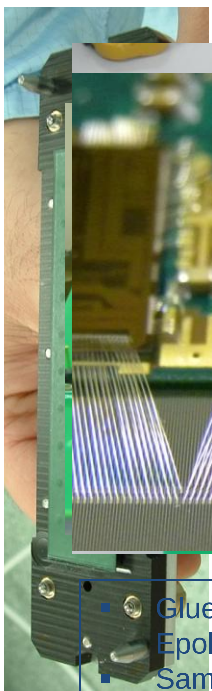
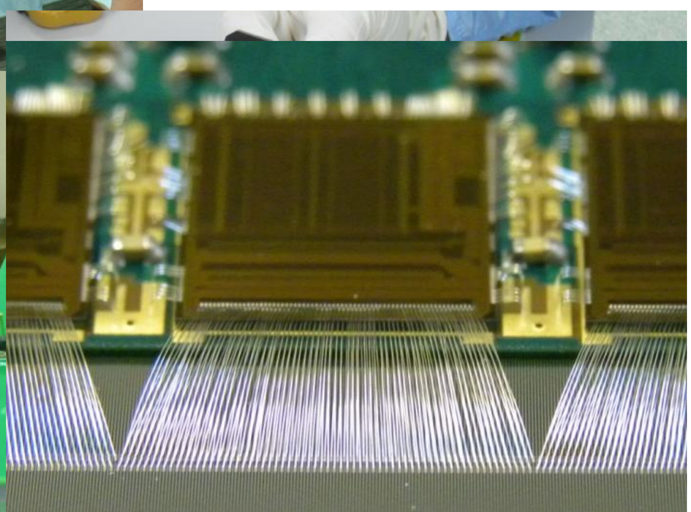
Stave Module Assembly

- Completed (substrate-less) hybrids have to be detached from the panel
  - Whilst maintaining integrity of circuit (no damaged wire bonds etc.)
- Solution is to use the same vacuum pickup tool as was used for ASIC attachment
  - With panel vacuum applied, hybrid retaining tabs are cut and then pickup tool attached
  - Apply vacuum to pickup tool and then release panel vacuum – circuit can then be lifted away





- Glue used for attaching hybrid to sensor is Epolite FH-5313 (electrical grade epoxy)
- Samples irradiated at CERN PS to 9.3×10^{14} n_{eq} cm^{-2} show no anomalous behaviour

Module Assembly steps

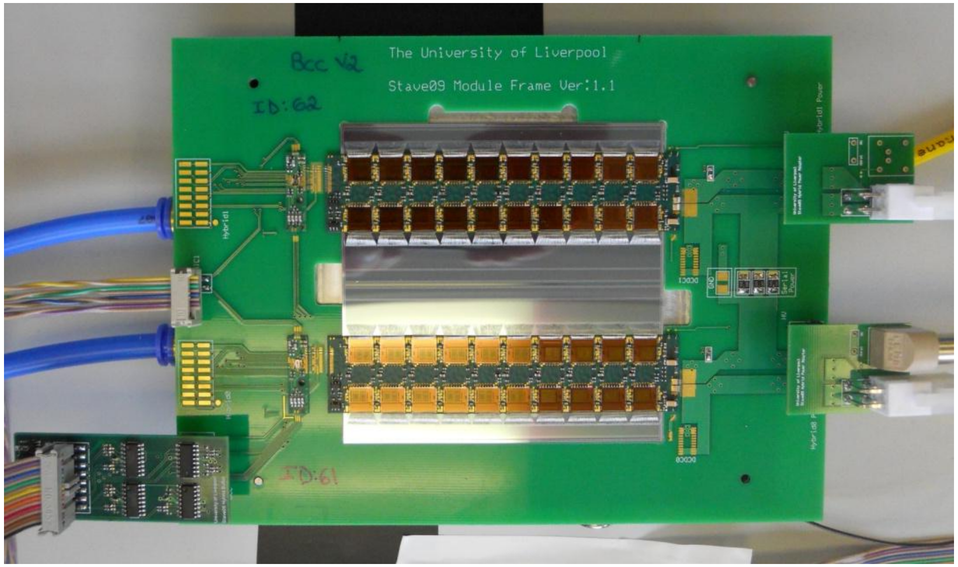
1. Make use of jig (with precision dowels and Kapton barrier) plus PCB frame.
2. With sensor in place, glue applied using 80µm thick paper stencil (glue compressed to ~40µm after assembly).
3. Ready to attach the flex to the sensor.
4. Place in position and leave to cure (repeat process for the second hybrid).
5. After completion, then go for wire-bonding (whilst in frame).

Stave Module – Electrical Performance

Two test scenarios:

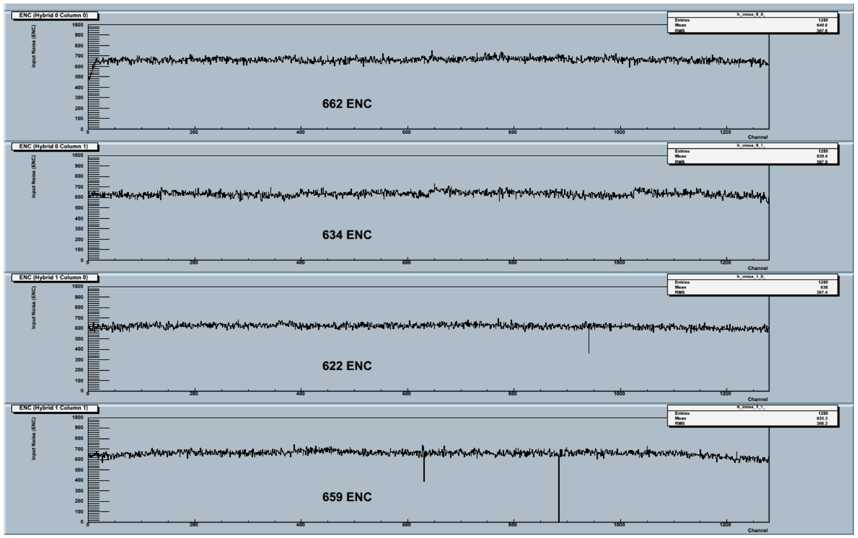
1. Test module with parallel powering - used as reference measurement
   - Both hybrids DC-referenced to sensor (and each other)

2. Serially powered
   - 2.5V per hybrid, ~5V total across the module (using constant current source)
   - One hybrid is DC referenced to sensor, the other AC
   - Use BCC ASICs for digital communication (AC-coupled LVDS), powered from hybrid



Stave Module – Electrical Performance

Parallel Powered (reference)



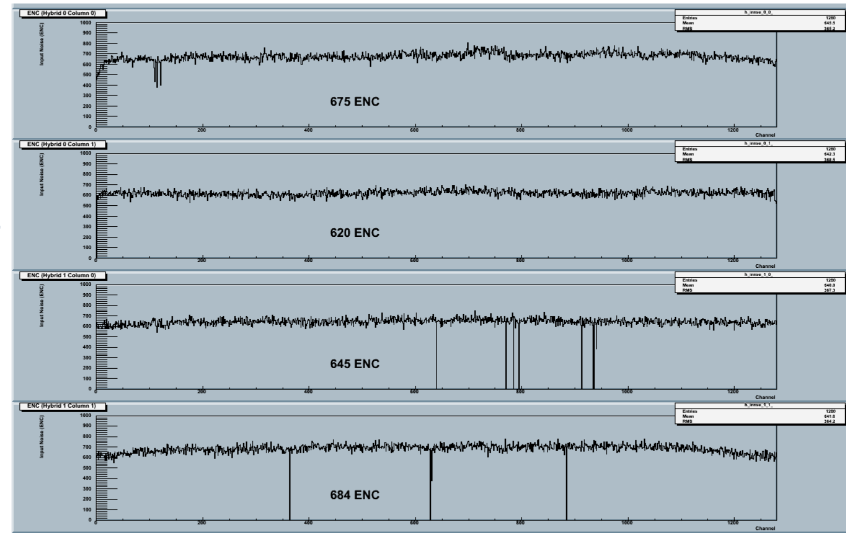
Column 0

Column 1

Column 2

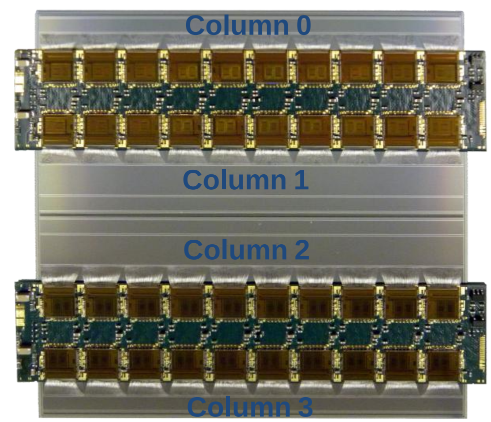
Column 3

Serially Powered



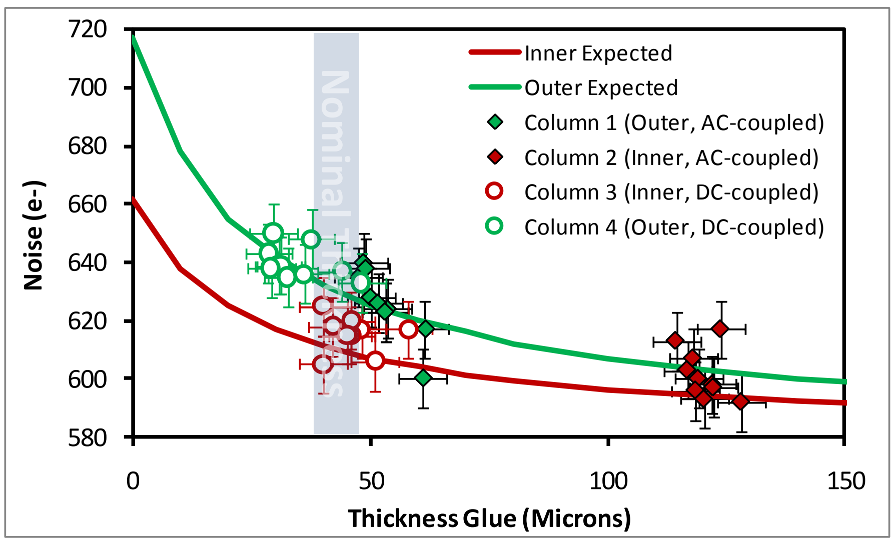
Serially Powered Module Works!

- Input Noise comparable between powering schemes
- Evidence of a noise signature seen on module(s)
  - Outer columns have higher noise compared to inner
  - Irrespective of powering scheme



Stave Module – Noise Signature

- Inner column strips have consistently lower noise compared to outer strips (~20e to 30e less)
  - Assumed it was an artefact of serial powering – but also seen with parallel powered module(s)
- Geometry of module - hybrids are attached asymmetrically on column boundary of sensor
  - Outer strips have 15mm coverage by hybrid whilst the inner strip coverage is 9mm
- Noise appears to be anti-correlated to glue thickness
  - Small number of hybrids have had glue in-fill added to their columns – they show reduced noise
- Points to increased load capacitance to ABCN-25 front-end from hybrid ground/shield



Present build of 40µm glue layer, expect ~610e on inner strips and ~630e for outer strips

- Plot of estimated noise contribution from shield as f^{unc} of glue thickness(scaled by inner and outer strip coverage)
- Data points added for noise measured from a Module. Reasonable agreement with estimation but evidence of glue thickness variation and tilt in hybrid relative to sensor

  Proposal is to either

- Retain shield but increase glue layer to 100µm
- Remove shield (further reduction of material)
  - Already done (yet to be tested)

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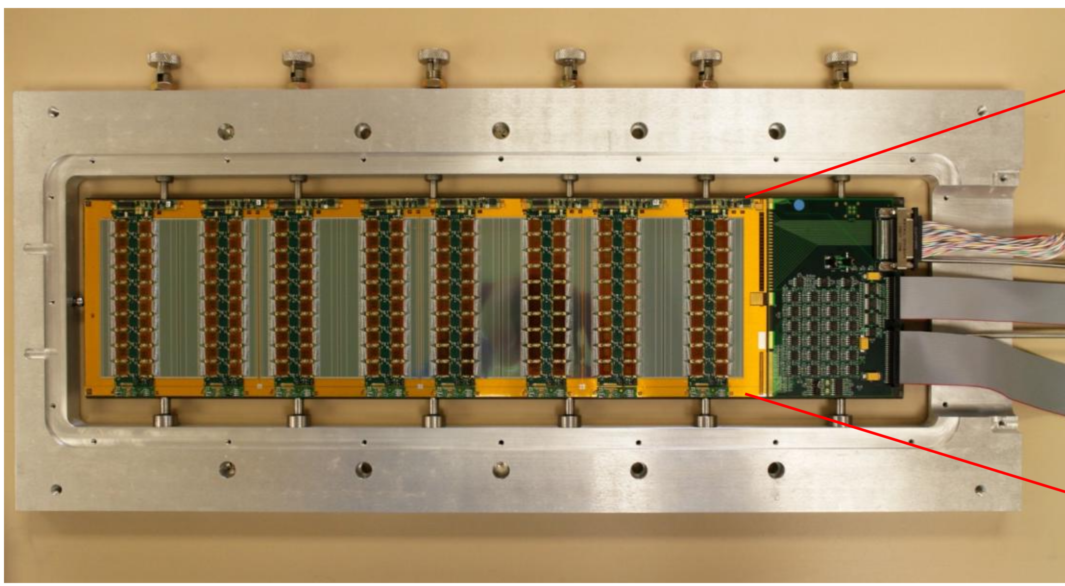
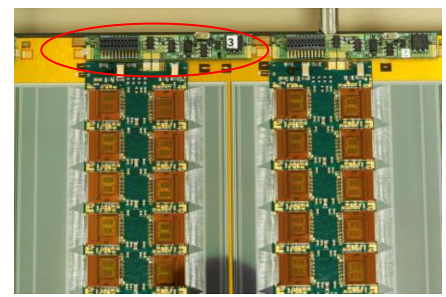
Short Stave Module Assembly – Stavelet

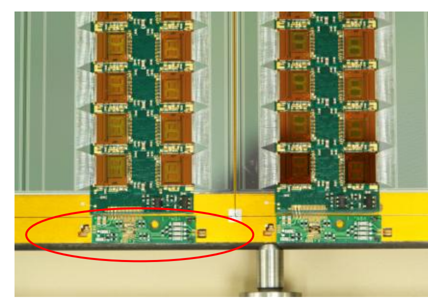
Stavelet: A test bed for serially powered multiple module studies

- 4 modules glued directly onto a stave assembly
  - Carbon structure with integrated cooling
  - Auxiliary support electronics: Serial power control (e.g. bypass), module data I/O
- Integrated bus cable
  - Serial power distribution, Sensor bias, Data I/O (multi-drop and point-to-point LVDS)



Serial Power Control (PPB)





Module Data I/O (BCC)

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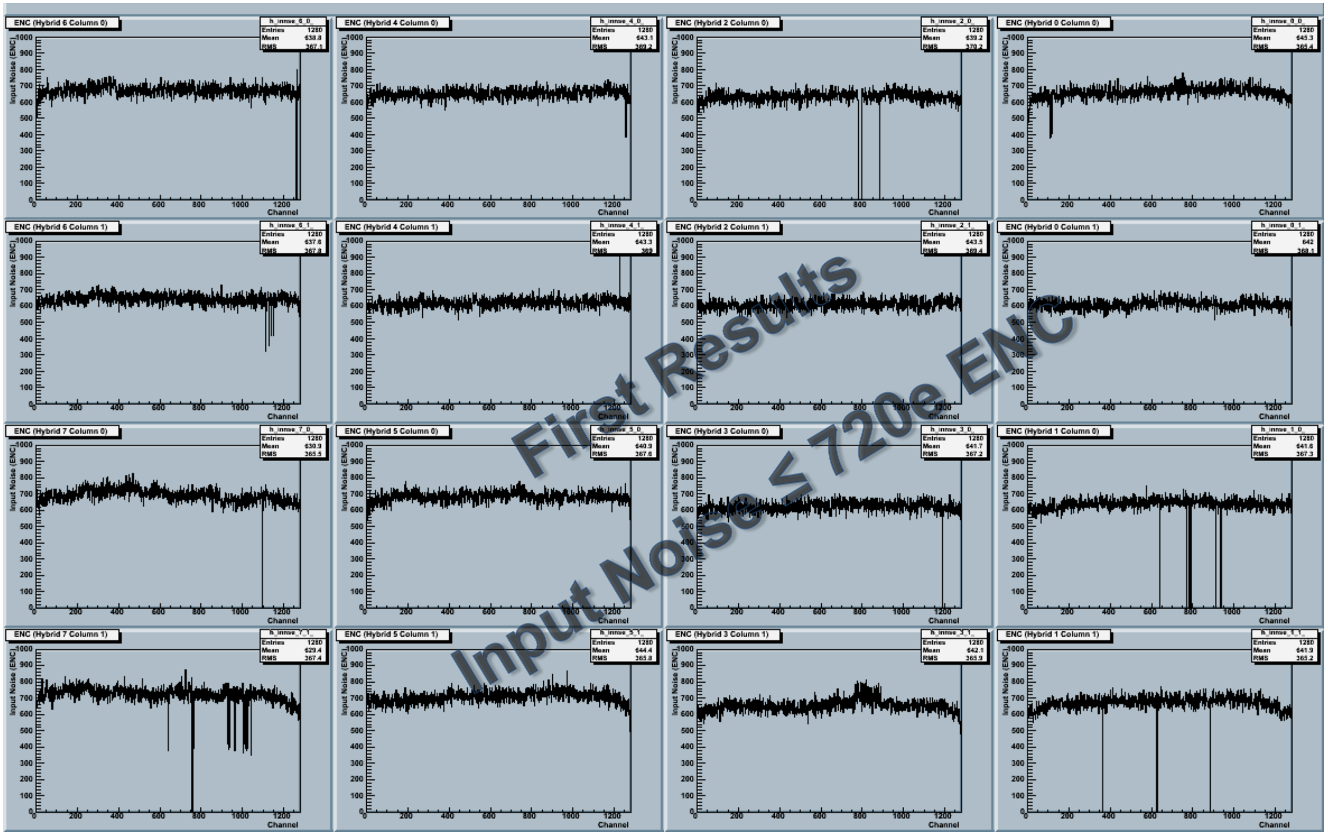
Short Stave Module Assembly – Stavelet

- 4 modules serially powered and readout at the same time
  - 8 hybrids, 16 data columns (mux'd onto 8 data streams) – 160 ASICs (>20k channels)

- **First results look very promising**



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Summary & Outlook

- Have successfully demonstrated the design and build of a substrate-less module
- Issues of yield and volume production being addressed from the outset
- Individually, serially powered modules, have been shown to perform excellently
- First tests of a serially powered multi-module short stave (Stavelet) are very promising

- Stavelet tests are ongoing (with future plans for a DCDC powered variant)
- Intention is to build a module using the new shield-less hybrids (reduced material)
- Longer term, the plan is to build a full size double-sided Stave composed of 24 modules

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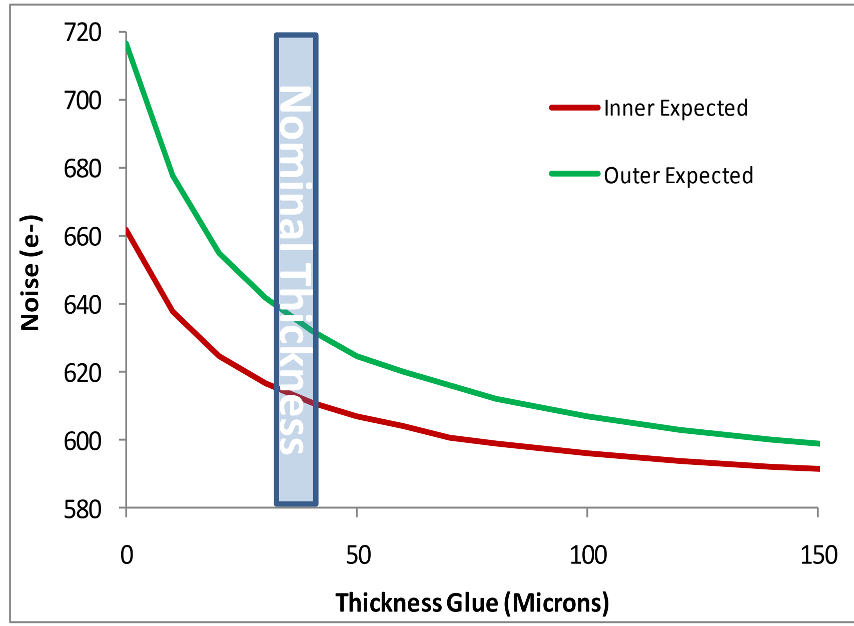
Thank you!

Back up

Noise contribution from shield

- Assume capacitance to shield in same manner as to sensor backplane
  - Take sensor backplane capacitance 0.26 pF/cm and ratios of sensor and glue + solder resist thicknesses (310 mm vs 25 mm + glue) and dielectric constant (11.4 vs 4.1) to get estimated load capacitance from shield layer per cm
  - Scale by coverage of inner and outer strips
- To calculate noise take expected noise slope (80 e^-/pF) and measured noise for double-sided module



Estimate for nominal glue of 40 µm expect ~610 e on inner strips and ~630 e on outer strips