Silicon Strip Detectors for the ATLAS HL-LHC Upgrade

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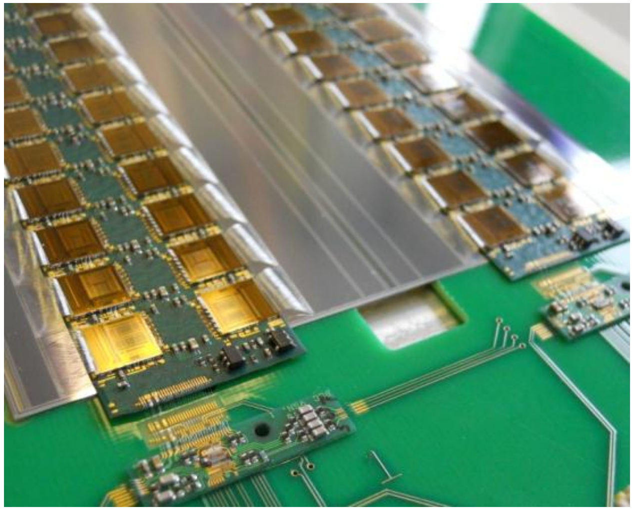
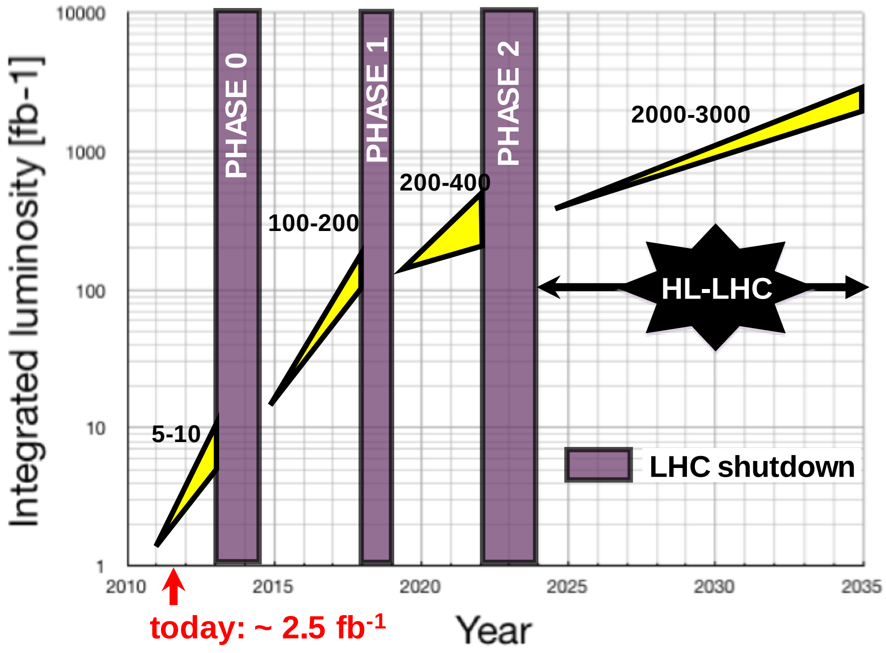
On behalf of the ATLAS Upgrade Community

Outline



- Introduction to the Upgrade
- Layout
- Si Sensors
  - Design
  - Performance
- Hybrid
- Modules
  - Performance
- Staves

ATLAS Inner Tracker Upgrades



Ten time increase in luminosity

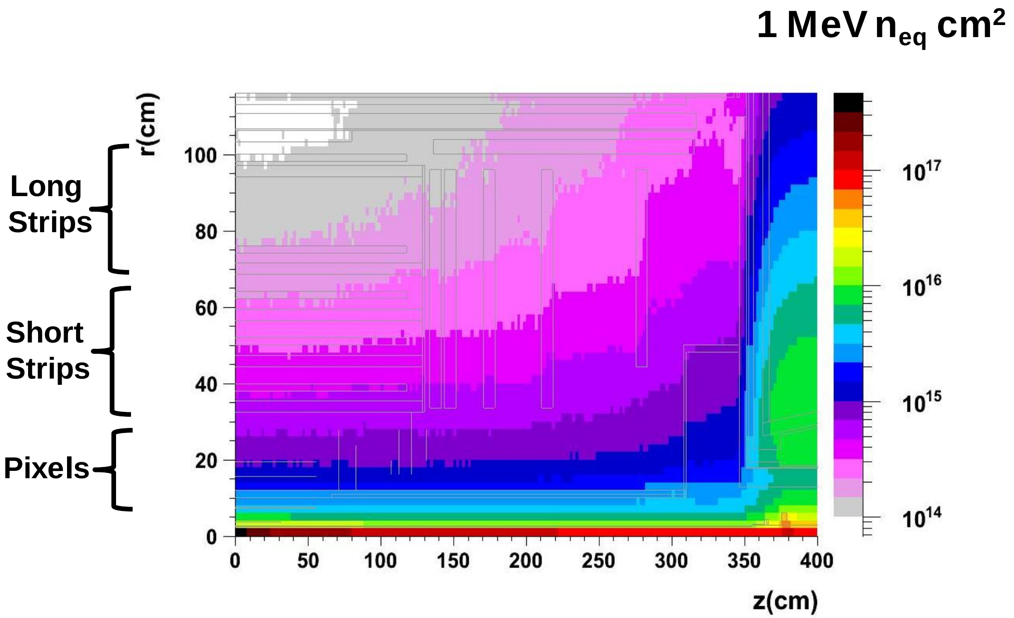
- **Phase 0**
  - **New Beam pipe w/additional pixel layer (IBL)**
- **Phase 1**
  - **Possibility of replacement of entire pixel system**
- **Phase 2 (HL-LHC, previously sLHC)**
  - **Replacement of current transition radiation tracker (TRT) and strip tracker with an all silicon tracker**

  Focus of this talk

ATLAS Phase II Tracker Upgrade

Challenges facing HL-LHC silicon detector upgrades:

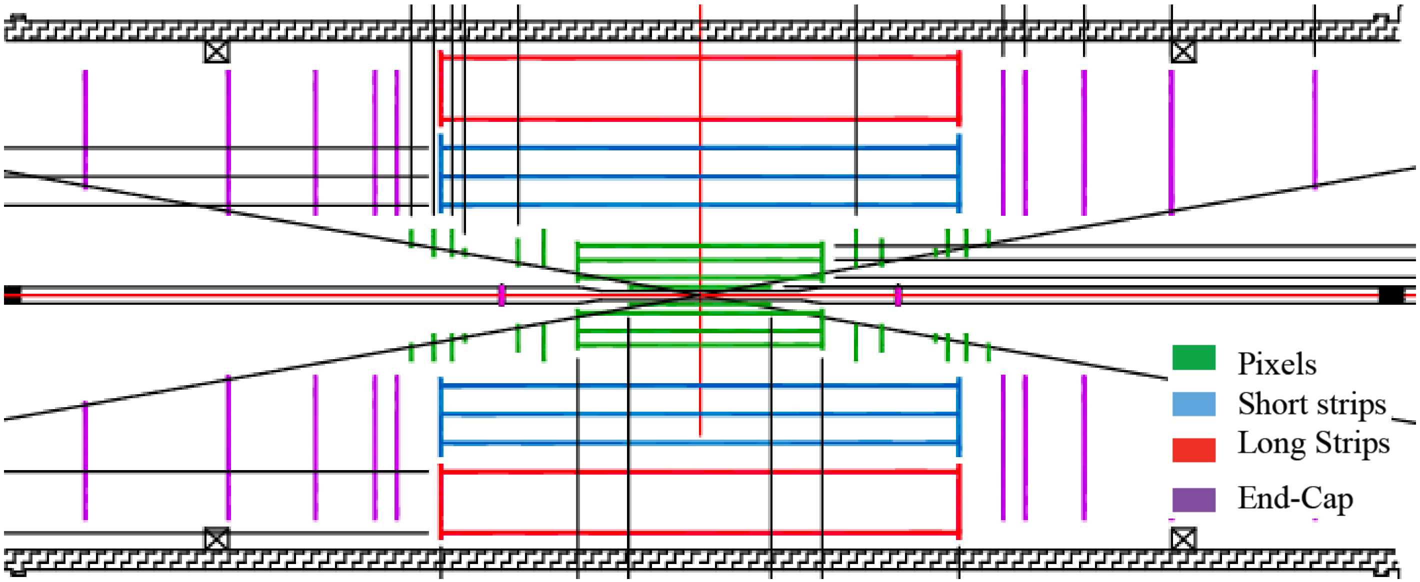
- Higher occupancies
  - ↳Finer Segmentation
- Higher particle fluences
  - ↳Increase Radiation Tolerance
- Larger Area (~200 m^2)
  - ↳Cheaper Sensors



Fluence estimates up to few 10^{16} particles/cm^2
Gives Grad (10 MGy) doses to components

Fluence estimates include a 2x "safety" factor for prediction uncertainties

ATLAS Phase II Tracker Upgrade

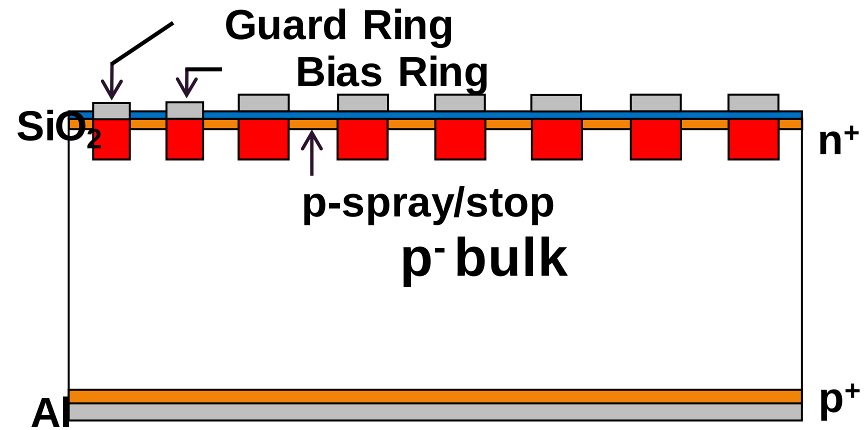


Short Strip (2.4 cm) μ-strips (stereo layers): r = 38, 50, 62 cm **Up to 1.2×10^{15} 1MeV n_{eq}/cm^2**

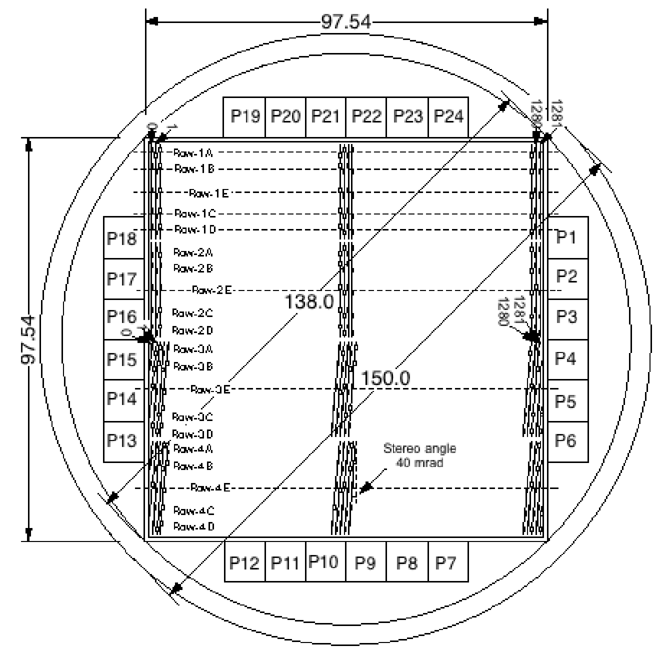
Long Strip (4.8 cm) μ-strips (stereo layers): r = 74, 100 cm **Up to 5.6×10^{14} 1MeV n_{eq}/cm^2**

Radiation Hard Sensors

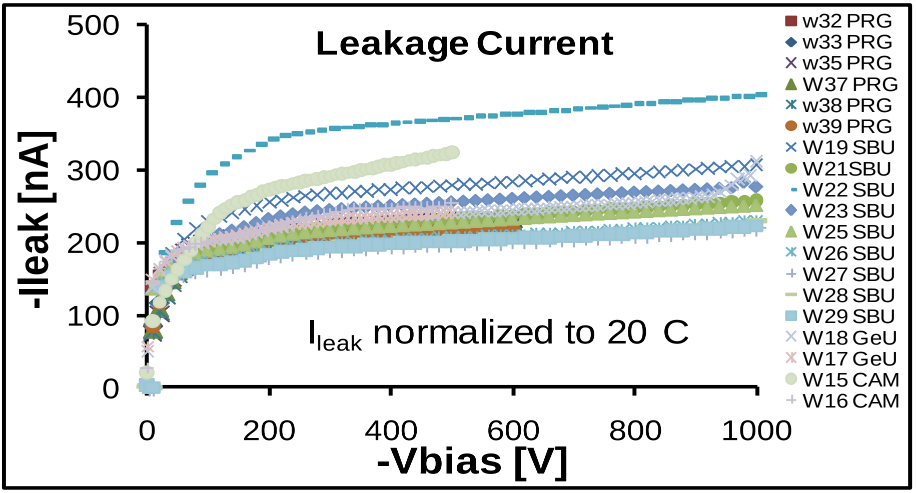
- n$^+$-strip in p-type substrate (n-in-p)
  - Collects electrons like current n-in-n pixels
    - Faster signal, reduced charge trapping
  - Always depletes from the segmented side
    - Good signal even under-depleted
  - Single-sided process
    - ~50% cheaper than n-in-n
    - More foundries and available capacity world-wide

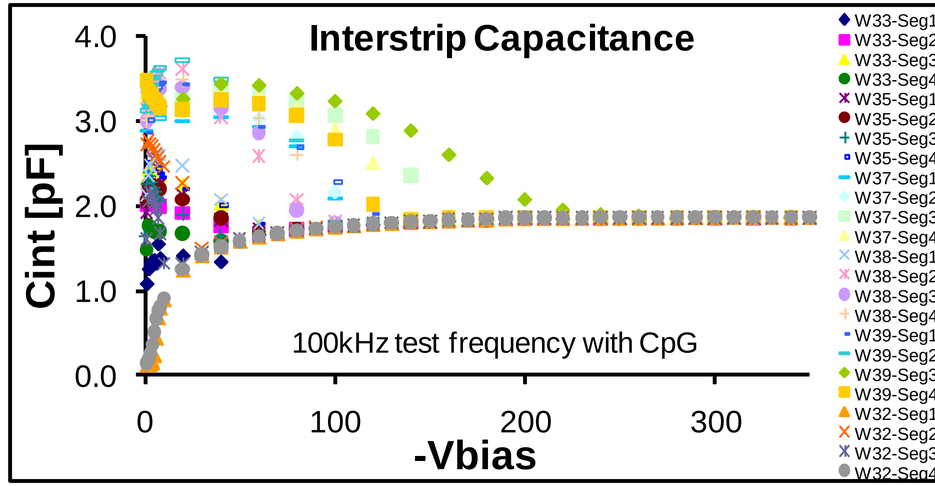


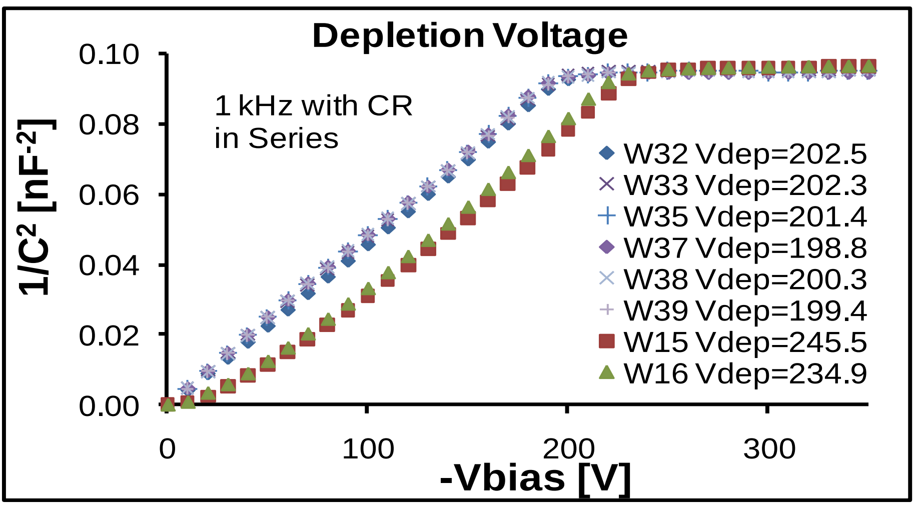
- Collaboration of ATLAS with Hamamatsu Photonics (HPK) to develop 9.75x9.75 cm^2 devices (6 inch wafers)
  - 4 segments (2 axial, 2 stereo), 1280 strip each, 74.5 mm pitch, ~320 mm thick
  - FZ1 <100> and FZ2 <100> material studied
  - Miniature sensors (1x1 cm^2) for irradiation studies



Full Size Sensor Evoluation





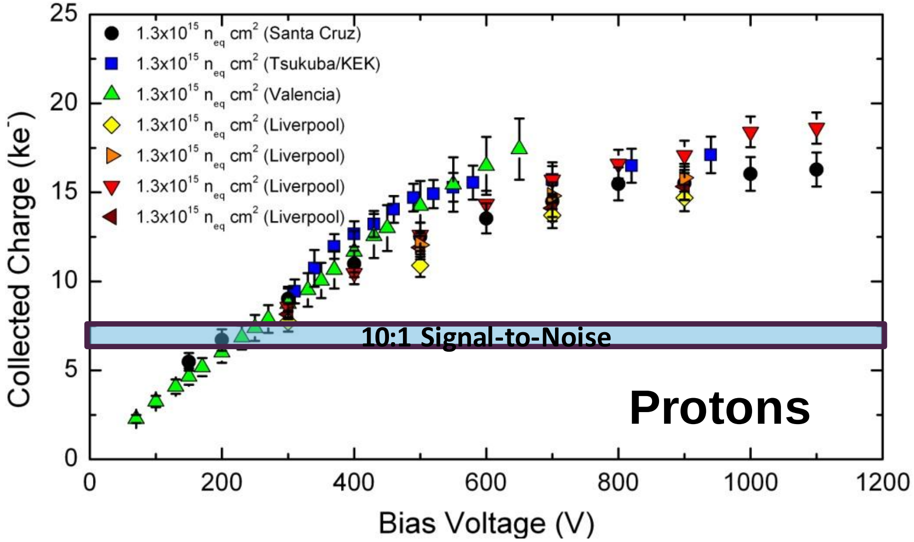


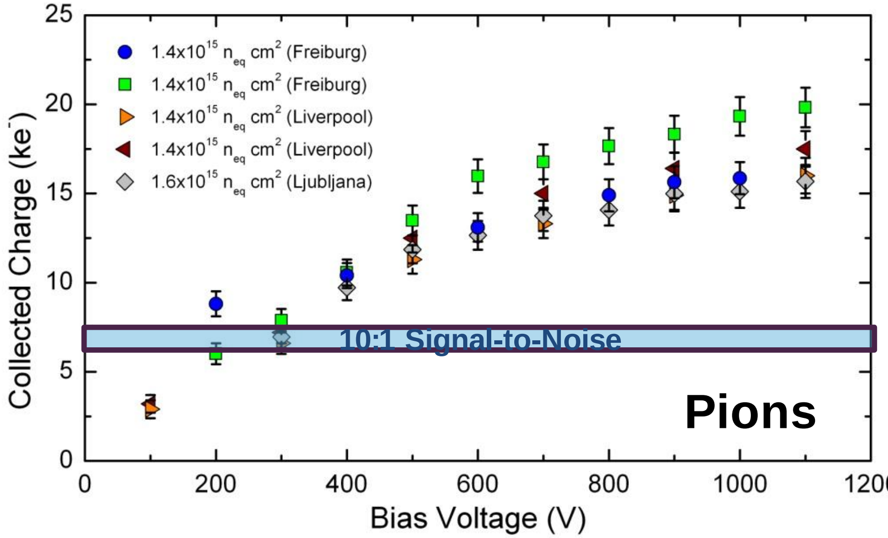
	Specification	Measurement
Leakage Current	<200 μA at 600 V	200– 370nA
Full Depletion Voltage	<500 V	190 – 245V
Coupling Capacitance (1kHz)	>20 pF/cm	24 – 30pF
Polysilicon Resistance	1.5+/-0.5MΩ	1.3 -1.6MΩ
Current through dielectric	I_{diel} < 10 nA	< 5nA
Strip Current	No explicit limit	< 2nA
Interstrip Capacitance (100kHz)	<1.1pF/cm (3 probe)	0.7 – 0.8pF
Interstrip Resistance	> 10x R_{bias}~15 MΩ	>19 GΩ

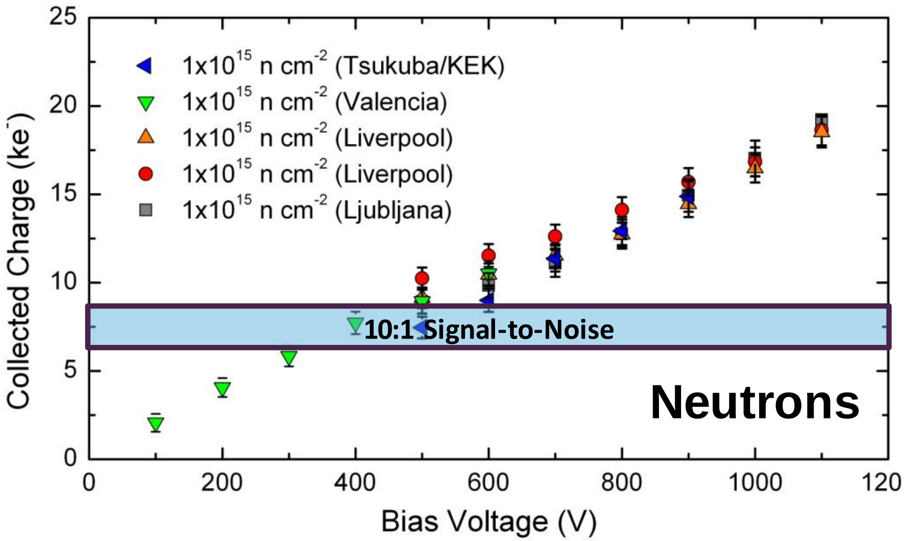
See J. Bohm, et. al., Nucl. Inst. Meth. A, Vol. 636 (2011) S104-S110 for details

All specifications already met!!

Charge Collection results



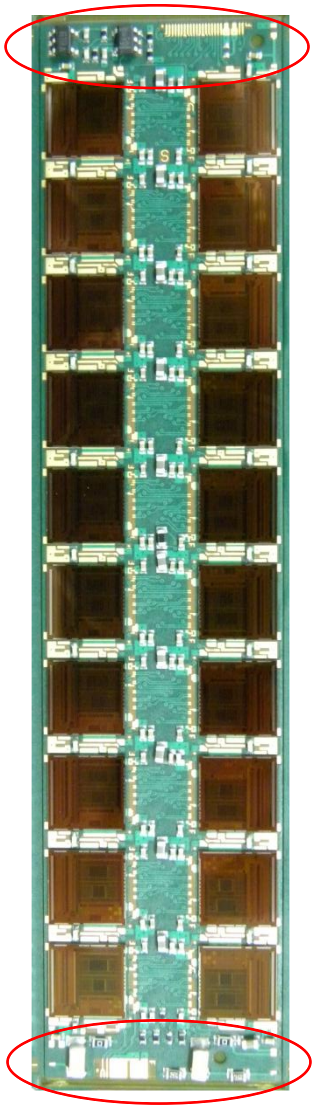




- **Miniature devices irradiated to strip barrel fluences with neutrons, pions, protons**
- **Charge collection measured with ^{90}Sr b-source**
  - **Consistent results between different groups/equipment**
- **S/N greater than 10:1 for strip sensor types with expected noise performance**
  - **~600-800 e⁻ short strips, ~800-1000 e⁻ long strips**
  - **See H. Sadrozinski, et.al., Nucl. Inst. Meth. A, doi:10.1016/j.nima.2011.04.0646 for details**

Stave Hybrid – Layout and Electrical Detail

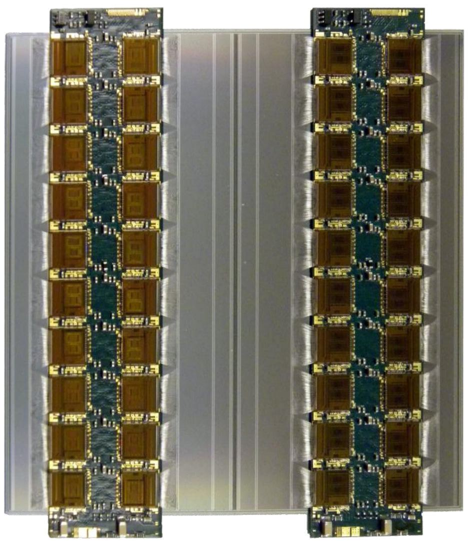
- **Hybrid is designed to accommodate 20 x ABCN-25 readout ASICs (2 columns of 10)**
- **Layout topology matches ATLAS07 large area sensor and serially powered Bus cable**
  - **ASICs placed to match sensor pitch and bond pad profile**
  - **Hybrid Power and Digital I/O bond fields at opposite ends**
- **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)

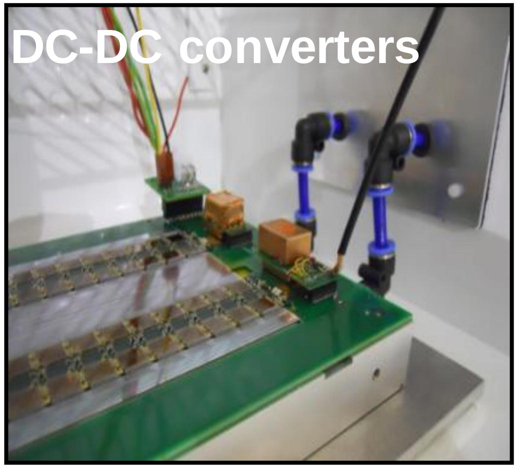
Stave Hybrid – Layout and Electrical Detail

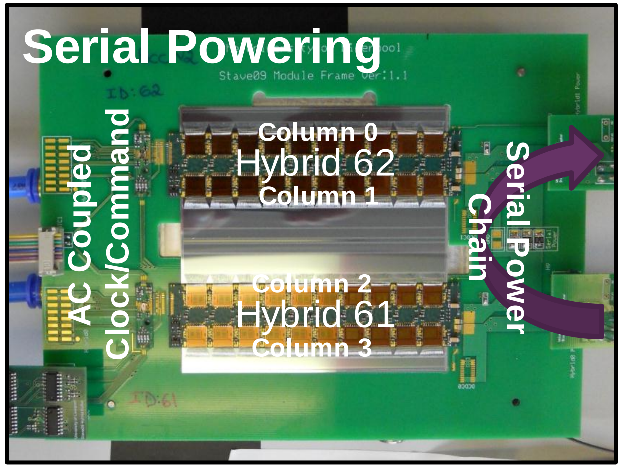


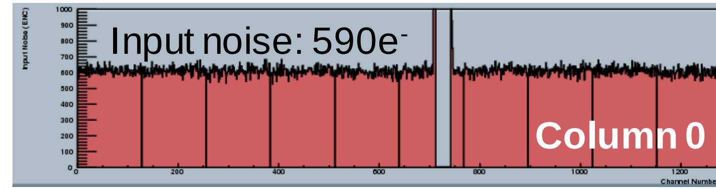
Design is driven by minimising material

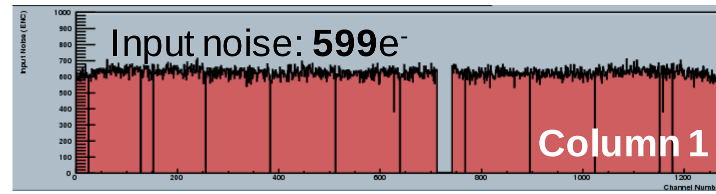
- Hybrid is substrate-less and with no connectors
  - Glued directly on to the sensor
    - Provides mechanical support and thermal management
  - All off-module connections made via wire bonds
- Use of minimal glue layers for both ASIC and hybrid attachment
  - Improves thermal paths and again reduces material
- Pitch adapters not used, direct ASIC-to-Sensor wire bonding
  - Constrains relative placement w.r.t. sensor to better than 80µm

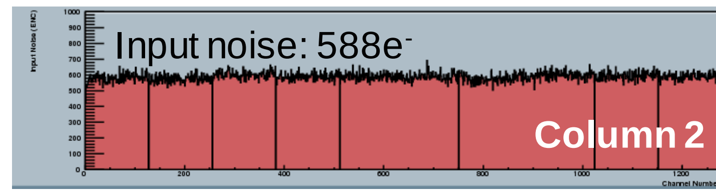
Stave Module Tests

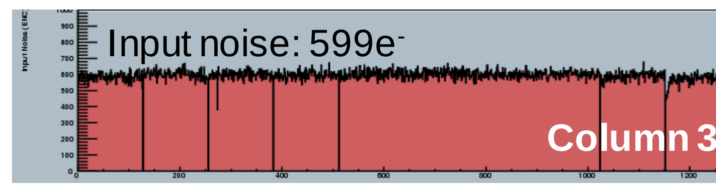








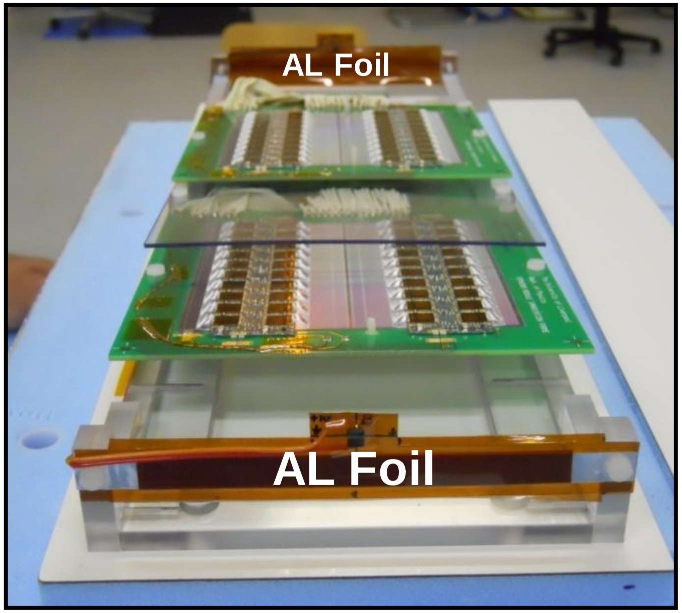




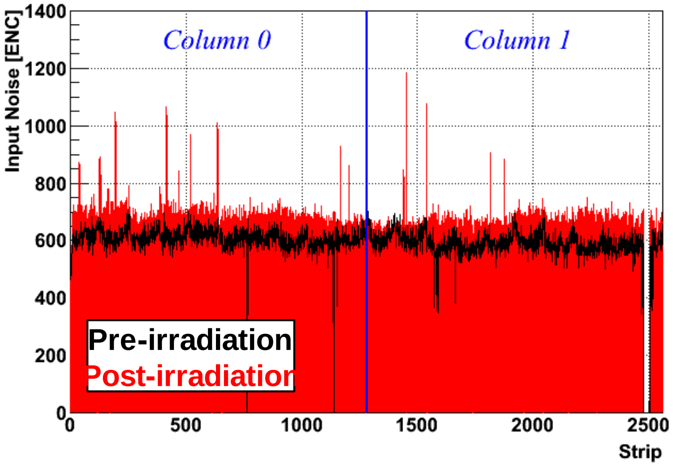
- **Stave modules are tested in PCB frames**
  - **Cheap, flexible test bed for different power/shielding/grounding configurations**
- **Parallel powering, serial powering, and DC-DC converters have all been evaluated**
  - **With proper grounding/shielding, all these configurations give expected noise performance**

	Parallel	Serial	DC-DC
Hybrid 62	590 e^- 596 e^-	590 e^- 599 e^-	595 e^- 603 e^-
Hybrid 61	585 e^- 591 e^-	588 e^- 599 e^-	585 e^- 591 e^-

Stave Module Irradiation



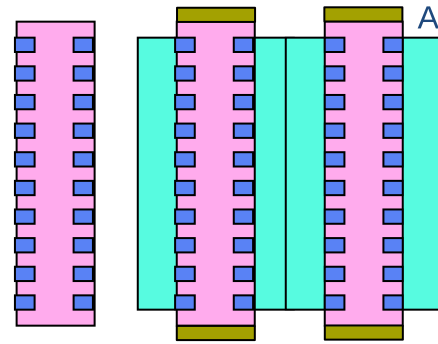
- Irradiated at CERN-PS irradiation facility
  - 24 GeV proton beam scanned over inclined modules
  - Module biased, powered, and clocked during irradiation
  - Total dose of 1.9×10^{15} n_{eq} cm^{-2} achieved
    - Max predicted fluence for barrel modules is 1.2×10^{15} n_{eq} cm^{-2}
- Sensor and module behave as expected
  - Noise increase consistent with shot noise expectations

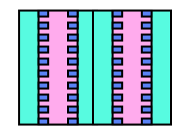


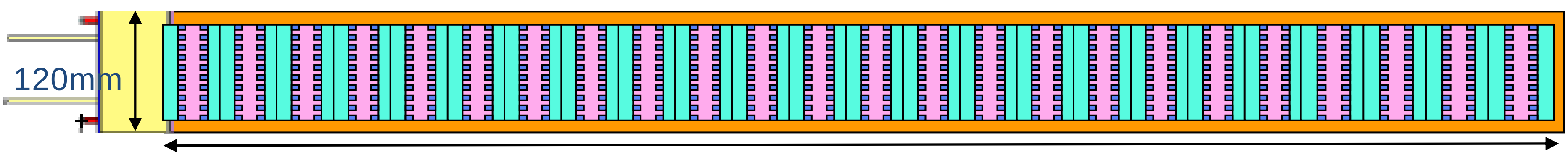
Noise	Column 0	Column 1
Pre-Irrad	610 e^-	589 e^-
Post-Irrad	675 e^-	650 e^-
Difference	65 e^-	61 e^-
Expected	670 e^-	640 e^-

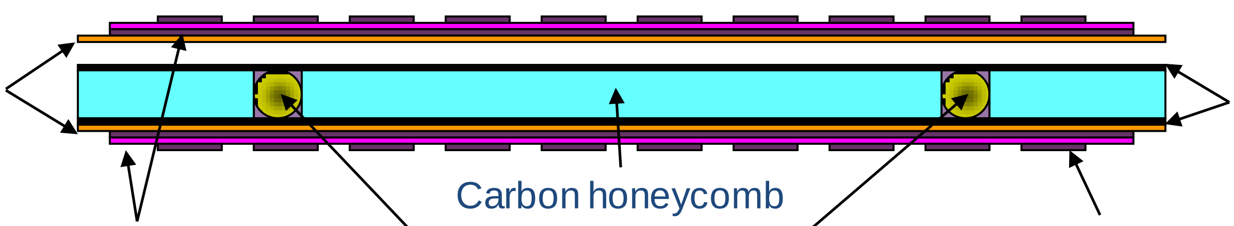
Stave – Geometry and components

- 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

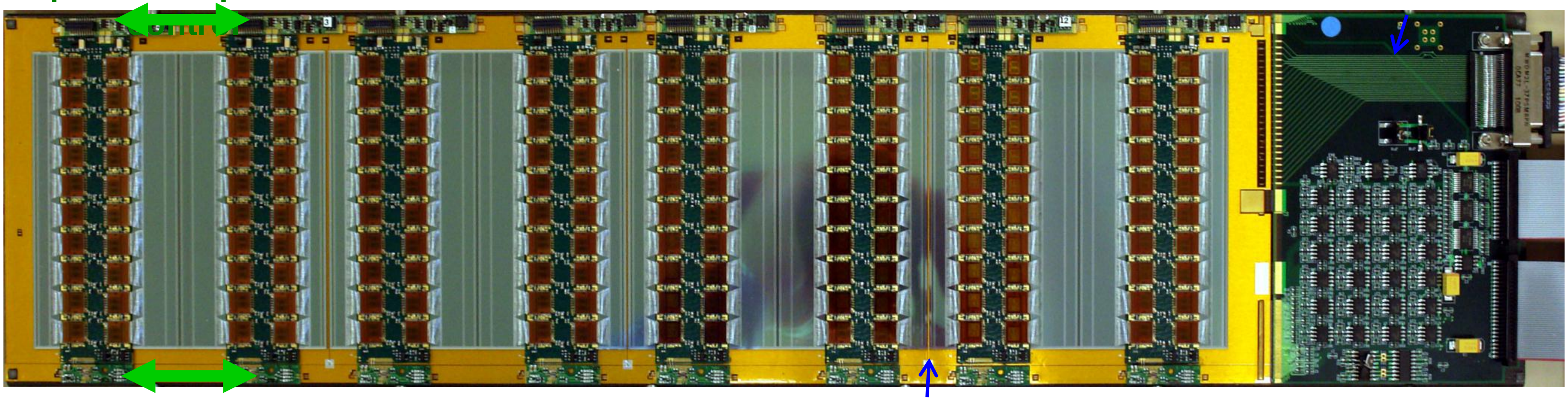








Stavelet

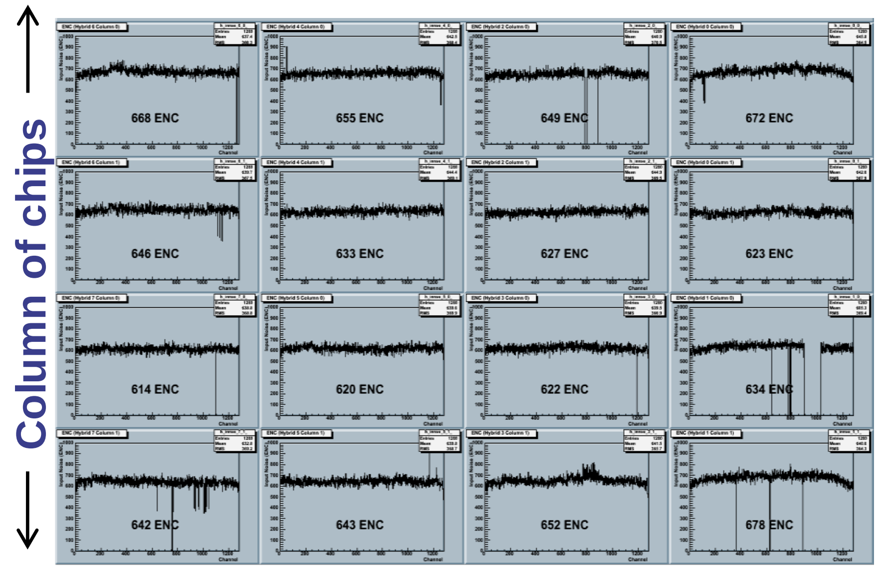


- Shortened stave built as electrical test-bed
  - Shielding, grounding, serial and DC-DC powering, …
- First stavelet serial powered
  - Power Protection Board (PPB) has automated over-voltage protection and slow-controlled (DCS) hybrid bypassing
  - <u>DC-DC stavelet under construction</u>
- Uses Basic Control Chip (BCC) for data I/O
  - Generates 80MHz data clock from 40MHz BC clock
  - 160Mbit/s multiplexed data per hybrid

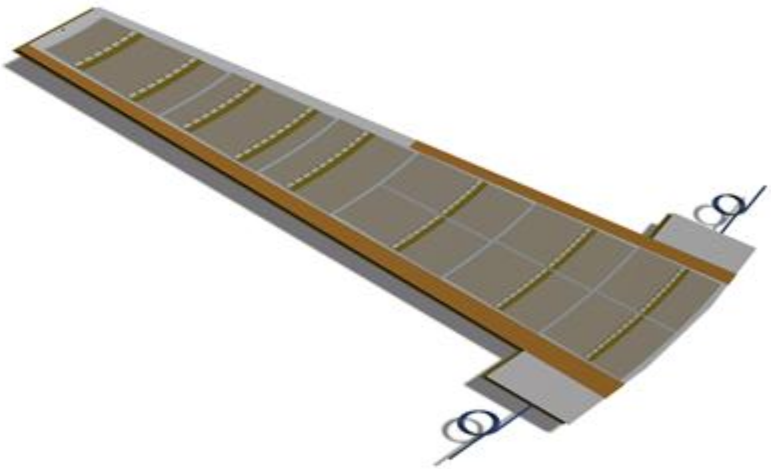
Serial Powered Stavelet Electrical Results

- Uses on-hybrid shunt control circuit
- Stavelet noise approaching single module tests
  - Roughly ~20 e^- higher
  - Bypassing hybrids does not affect noise performance
- All technologies necessary for serial powering of stave have been prototyped and shown to work (and compatible with 130 nm CMOS)
  - Constant current source, SP protection and regulation, multi-drop LVDS
    - Currently optimizing location of components, size of SP chains
- Minimal impact on material budget
  - Estimated to be ~0.03% averaged over the stave

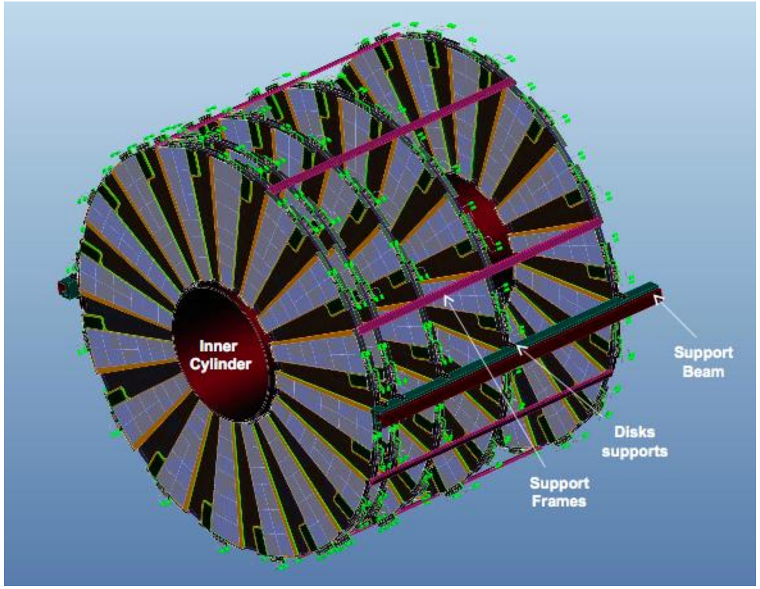
Stavelet Noise using Serial Power

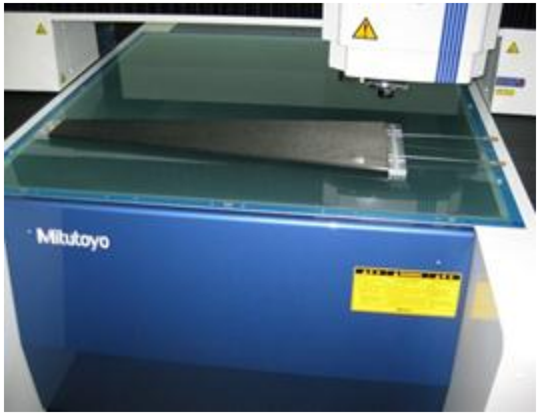


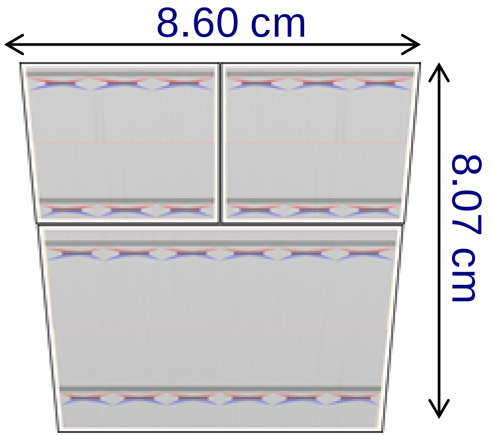
Petal Endcaps



- The petal concept follows closely the barrel stave concept
- 5 discs on each end cap with 32 petals per disc
  - 6 Sensor rings
- First petal cores have been produced
  - Flat to better than 100 μm
- First endcap hybrids tested
  - Same performance as barrel hybrid
- n-in-p sensor prototypes submitted to CNM to make petal-let using 4” wafers

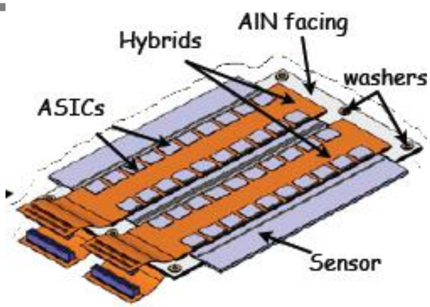


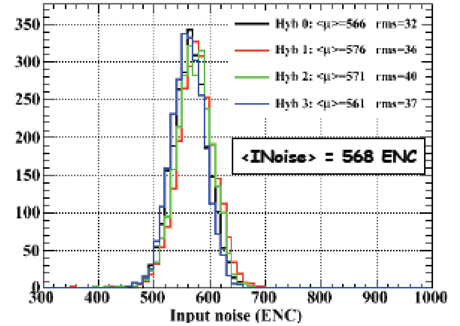


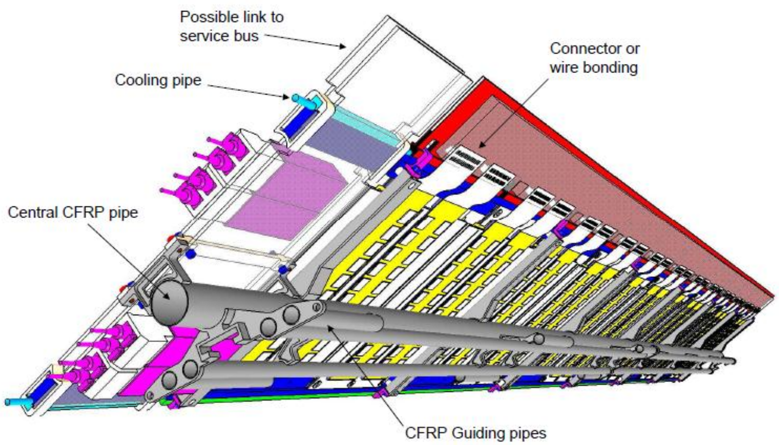


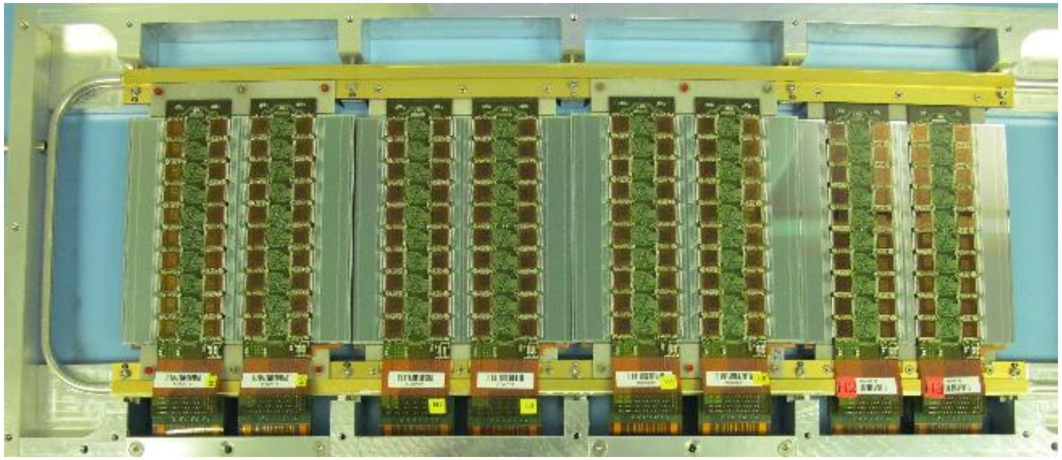
Alternative Solution: Super Module

- Modular concept: cooling, local structure, service bus, power interface are decoupled from the modules
- Overlapping coverage in Z
- Rework – Possible up to the commissioning after integration
- Design includes carbon-carbon hybrid bridge
  - Hybrid could be also glued as for stave modules to reduce material









Conclusions

- The current ATLAS TRT and silicon strip tracker must be replaced with an all-silicon tracker for HL-LHC operation (planned to be assembled by 2020)
- The R&D program of components has made significant progress:
  - Full-size prototype planar strip detectors have already been fabricated at Hamamatsu Photonics (HPK) which meet the final specifications
  - Working baseline and alternative module prototypes have been made and shown to work after irradiation
- Full-size stave/super-module prototypes are planned to be finished this year with the next generation of the 130 nm ASICs for the strip tracker under design