



Overview of hybrid and module developments for the CMS and ATLAS outer tracker upgrades

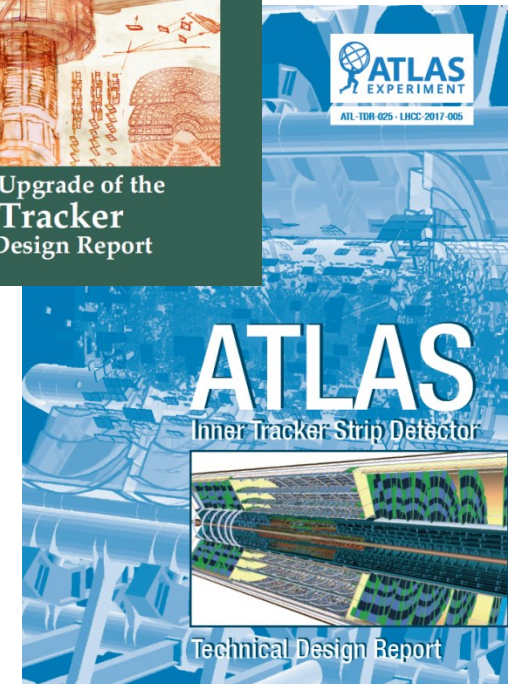
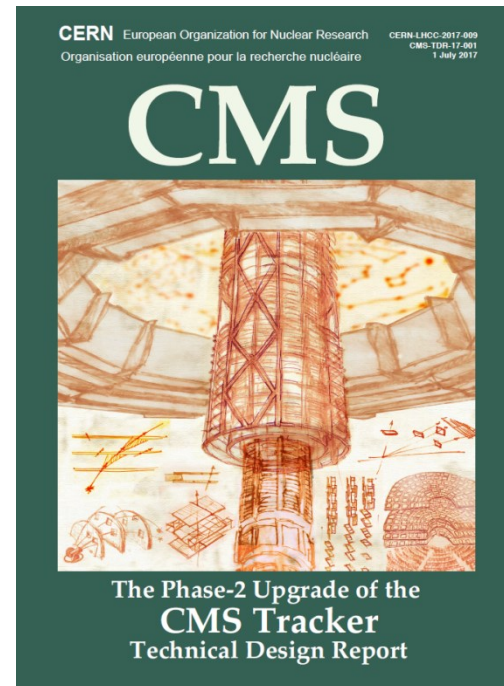
Craig Sawyer
STFC Rutherford Appleton Laboratory

ACES 2018

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Introduction

- 2026 will see the start-up of an upgraded LHC (HL-LHC)
- In the preceding shutdown (LS3) major experimental upgrades will be installed including new all-silicon trackers in both ATLAS and CMS
- TDRs for the ATLAS ITk Strip Detector and the CMS tracker were released last year
- A third TDR for the ATLAS Pixel Detector is being released this year
- Today I will concentrate on the outer trackers of the two experiments
- I will show similarities and differences between the two designs

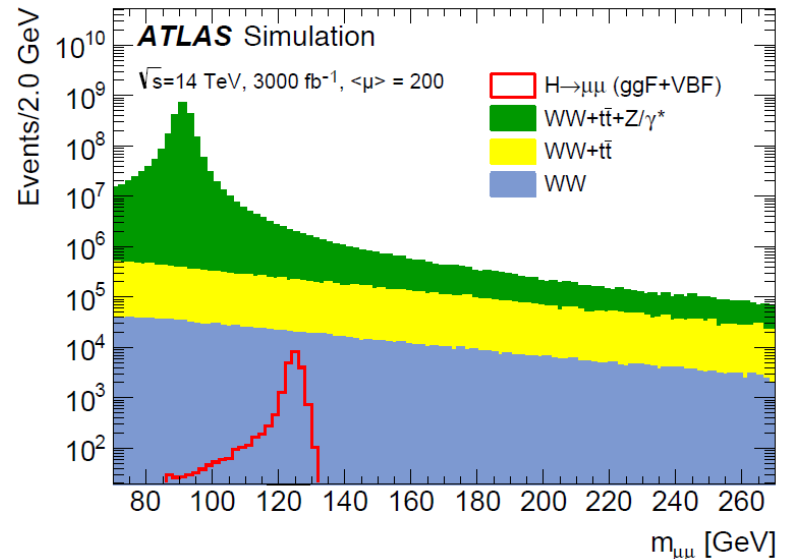
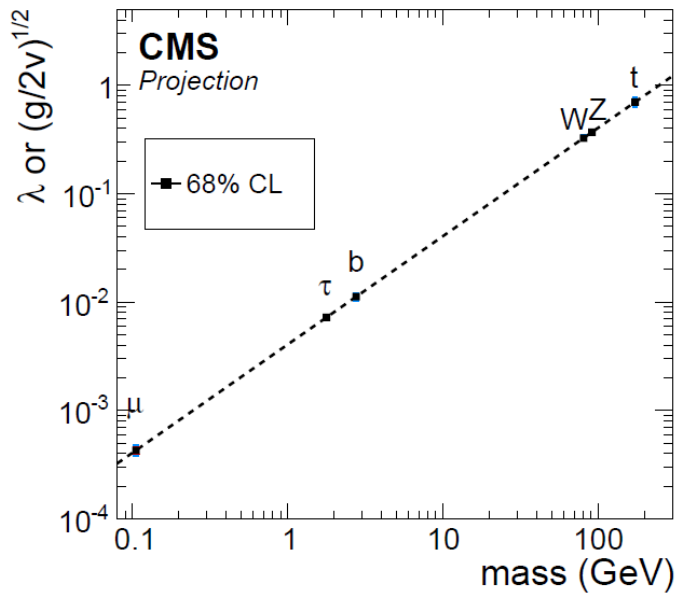
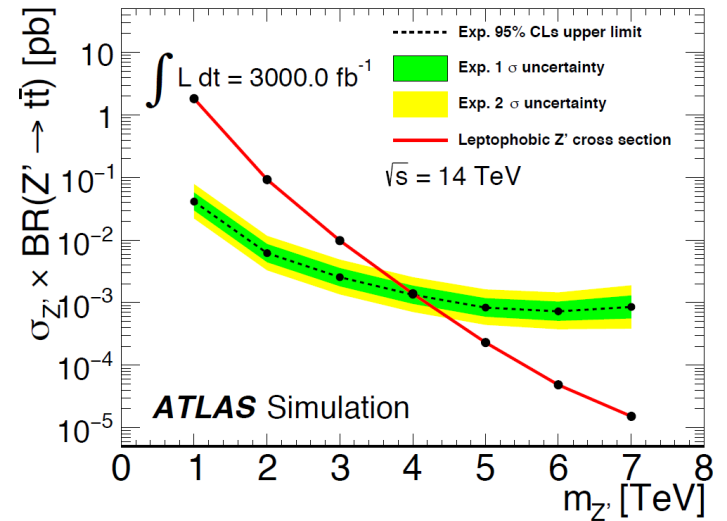
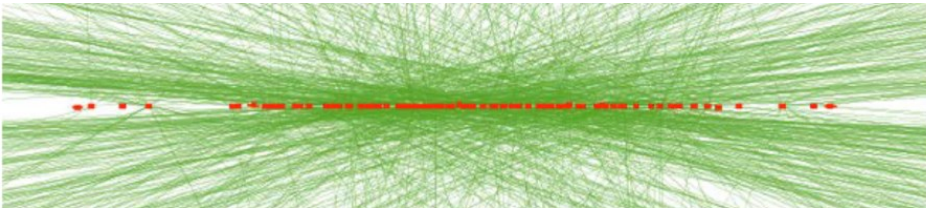


Upgrade Motivations

LHC (25 vertices)

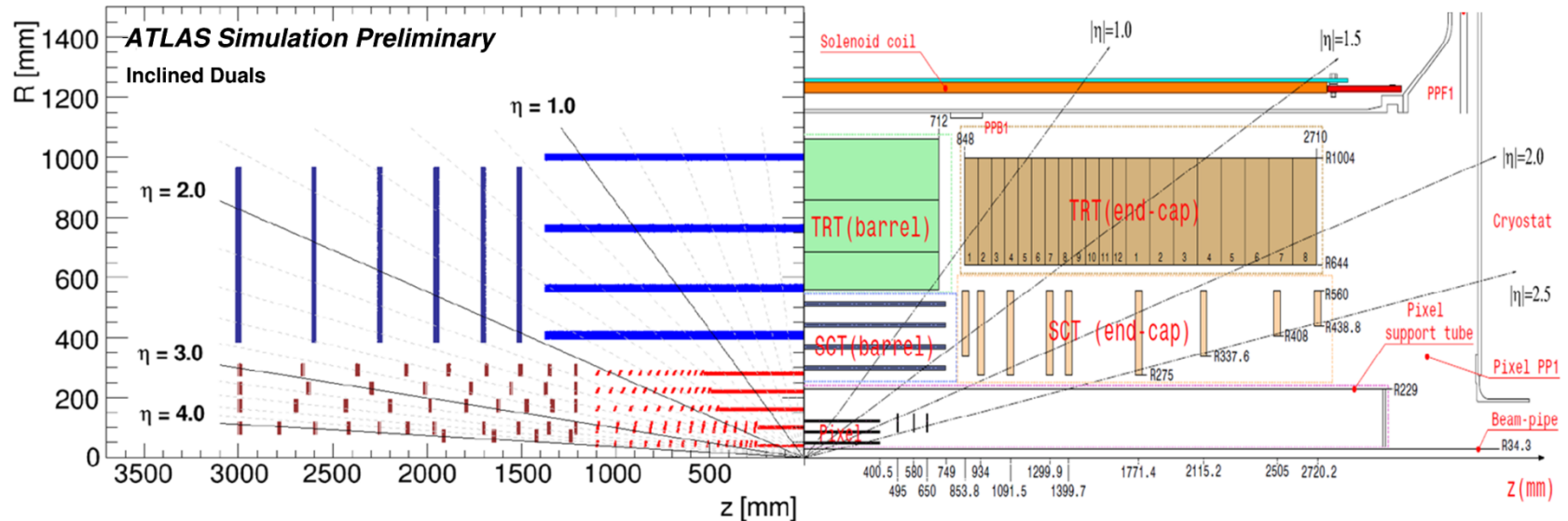


HL-LHC (200 vertices)



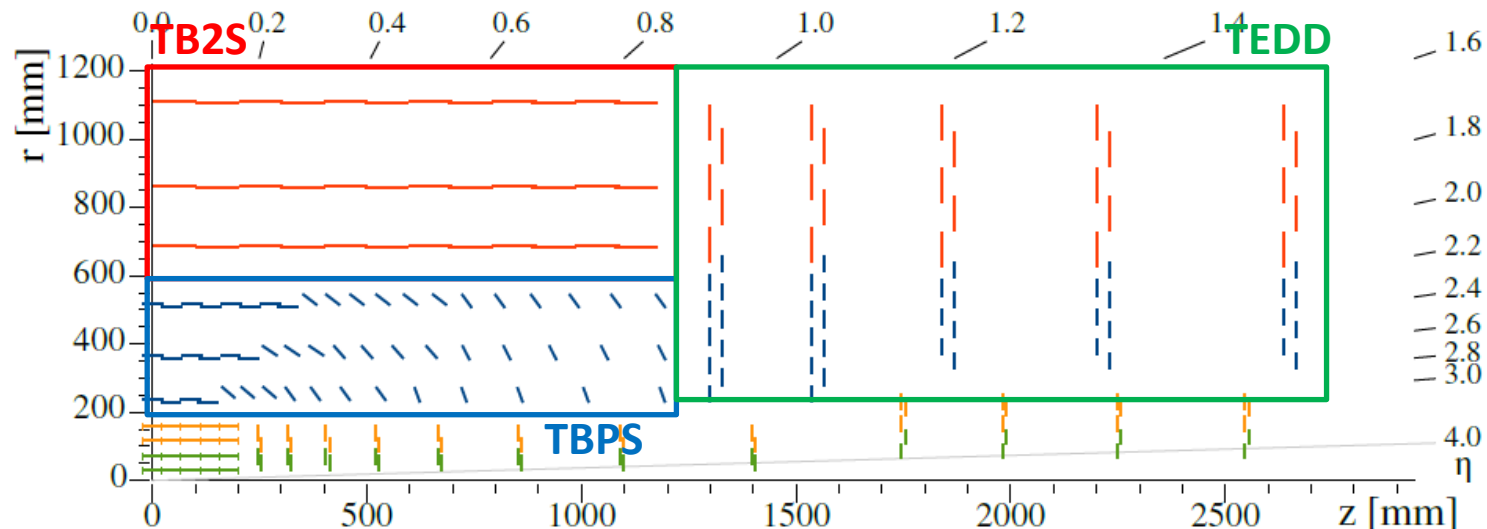
ATLAS ITk Strip Detector - Concept

- Strip barrel made of 4 double sided barrel layers
 - Two outer layers of “long” strips of 48 mm, 75.5 μm strip pitch
 - Two inner layers of “short” strips of 24 mm , 75.5 μm strip pitch
- 6 double sided end-cap disks
 - Strip length varies with radius from 18-60 mm and pitch from 69.9-80.7 μm
- Along with 5 layer pixel system provides tracking coverage up to $|\eta| < 4.0$
- Stereo angle of $\pm 26\text{mrad}$ in barrel by placement of modules on local support
- Stereo angle of $\pm 20\text{mrad}$ implemented in sensor design

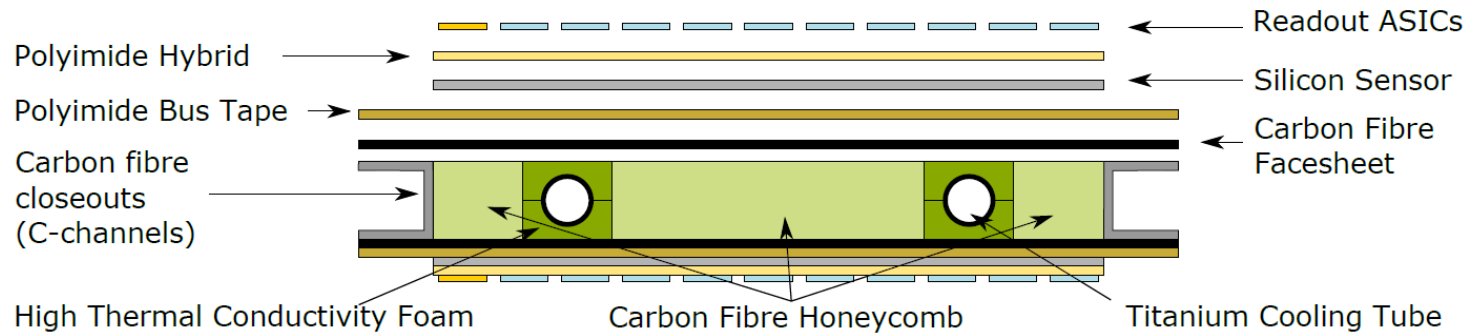


CMS Outer Tracker - Concept

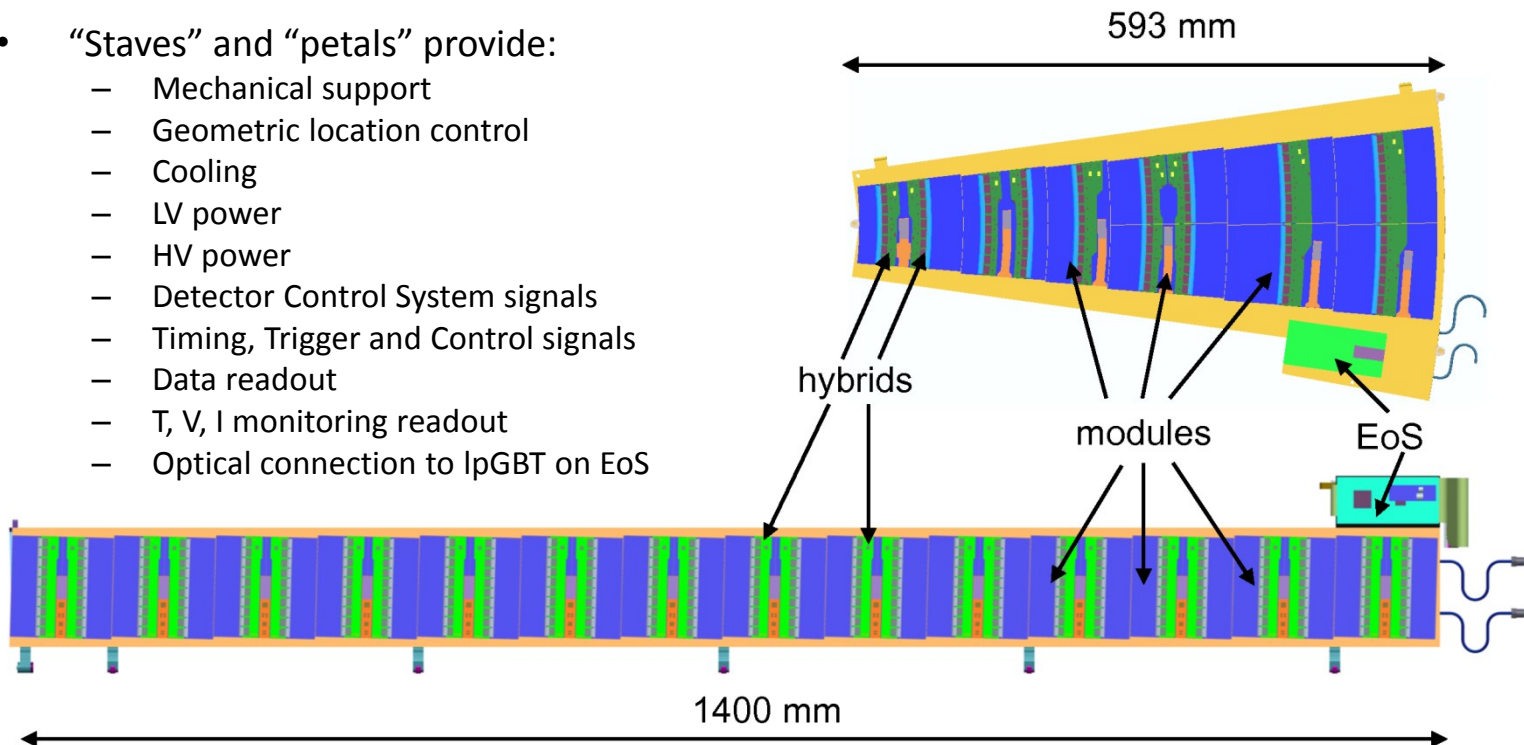
- TBPS made of 3 layers of hybrid pixel-strip modules (PS)
 - Strip sensor with 24 mm long strips with 100 μm pitch
 - Pixel sensor with 1.5 mm long “macro-pixels” with 100 μm pitch
- TB2S made of 3 layers of double sided strip modules (2S)
 - 50 mm long strips with 90 μm pitch
- 5 double disks make up the end-cap
 - Made of mixture of PS and 2S modules
- Along with 4 layer pixel system provides tracking coverage up to $|\eta| < 4.0$
- No stereo angle implemented due to track trigger requirements (see later)



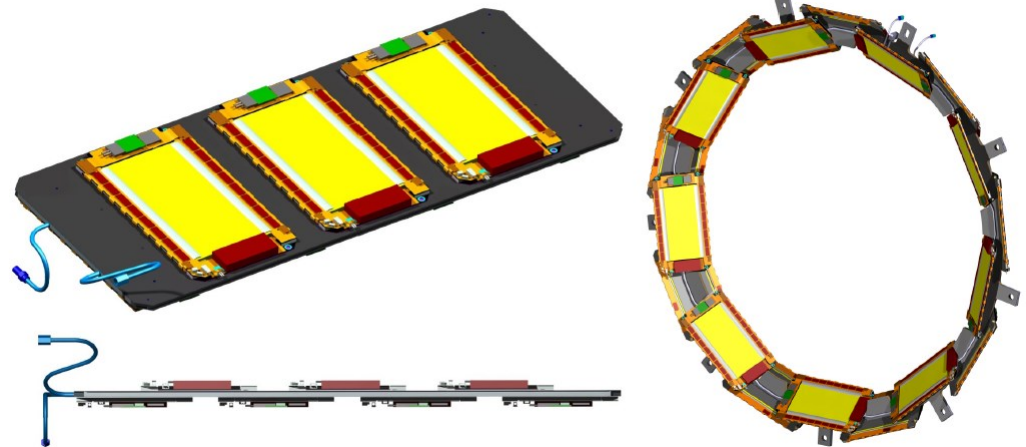
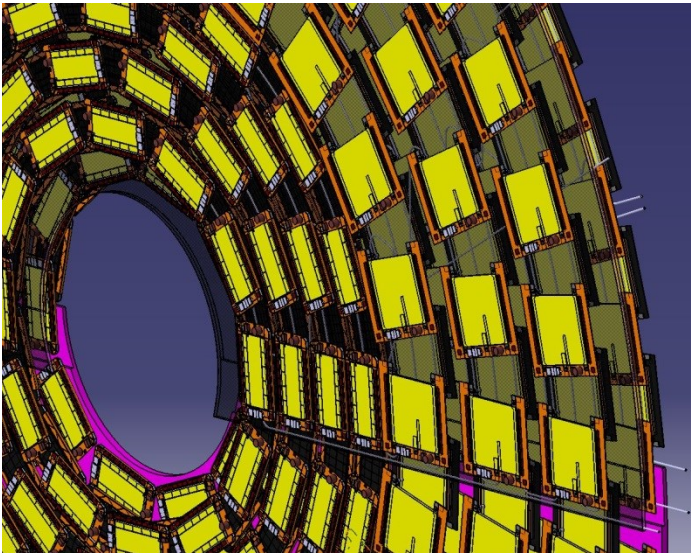
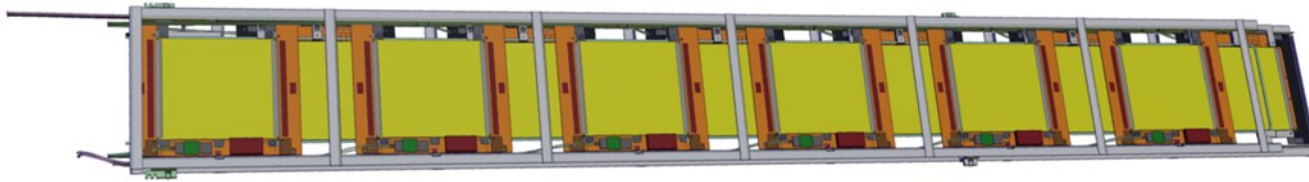
ATLAS ITk Strip Detector – Local Support



- “Staves” and “petals” provide:
 - Mechanical support
 - Geometric location control
 - Cooling
 - LV power
 - HV power
 - Detector Control System signals
 - Timing, Trigger and Control signals
 - Data readout
 - T, V, I monitoring readout
 - Optical connection to IpGBT on EoS



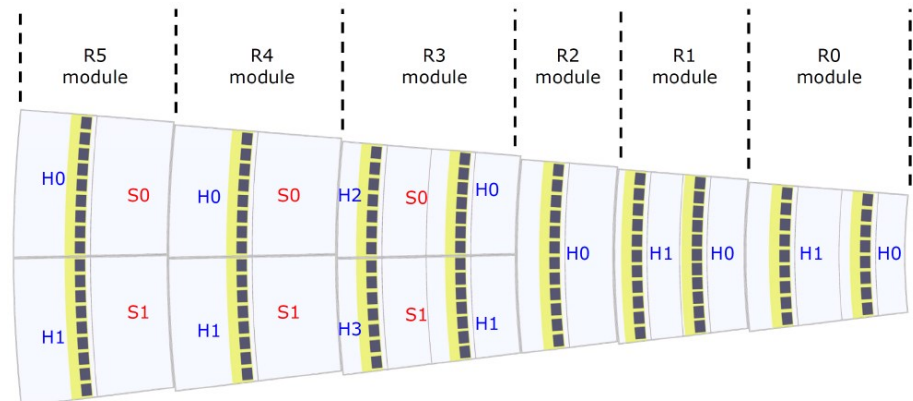
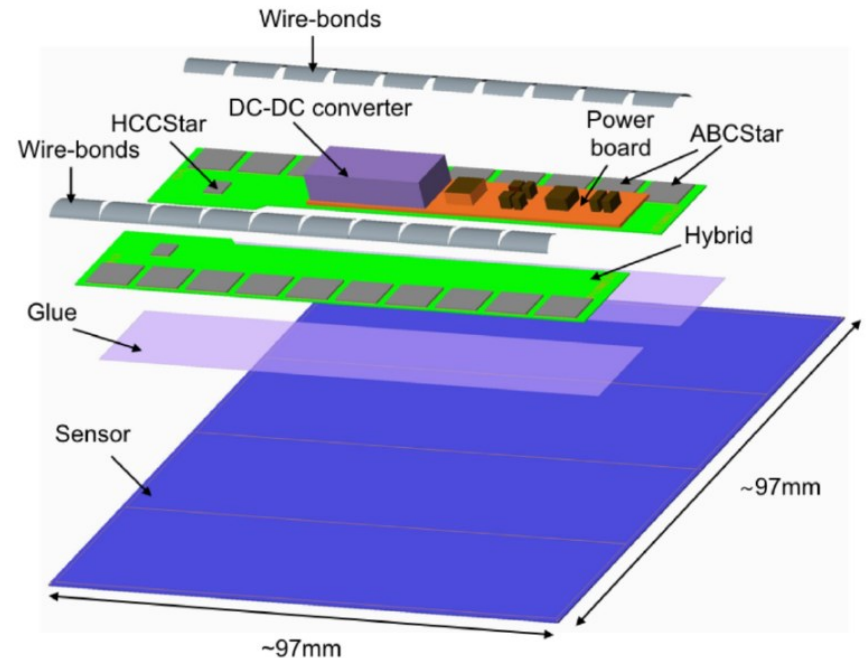
CMS Outer Tracker – Local Support



- 2S modules screwed to “ladders”
 - Each module has individual optical connection for communication and readout
- PS modules on “planks” and “rings”
- End-cap modules loaded on “double disk” structure

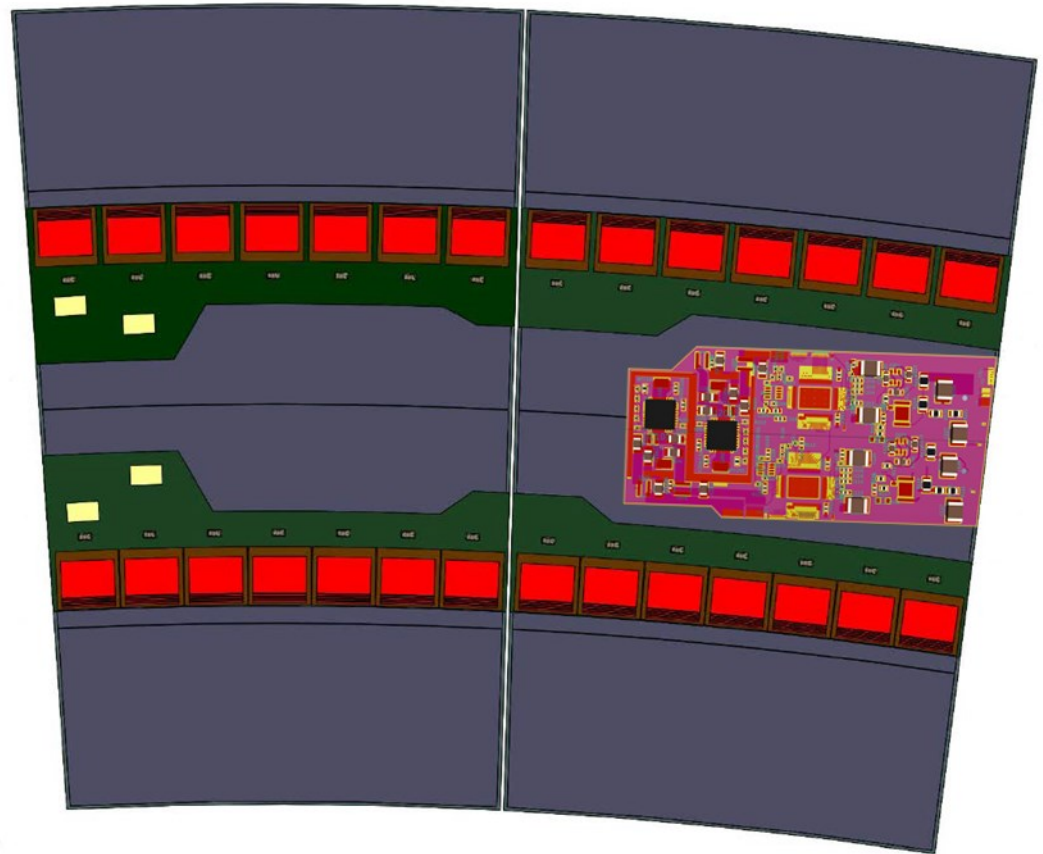
ATLAS ITk Strip Detector - Modules

- 10x10 cm n-in-p sensor
- Hybrids and powerboard glued directly to sensor surface
 - Provides for a fully integrated module with good thermal management
- ABCStar FE ASICs
 - 256 channels per chip
 - Point-to-point data connection to HCCStar
- HCCStar controller chip
 - Forwards data to IpGBT on EoS
- All interconnections done via aluminium wire-bonds
- Sensor HV bias via polyamide aluminium “tab” bonded directly to backplane (not shown)
- 2 module variants in the barrel (long/short strips)
- 6 module variants in the end-cap
- All modules have same architecture with different geometries

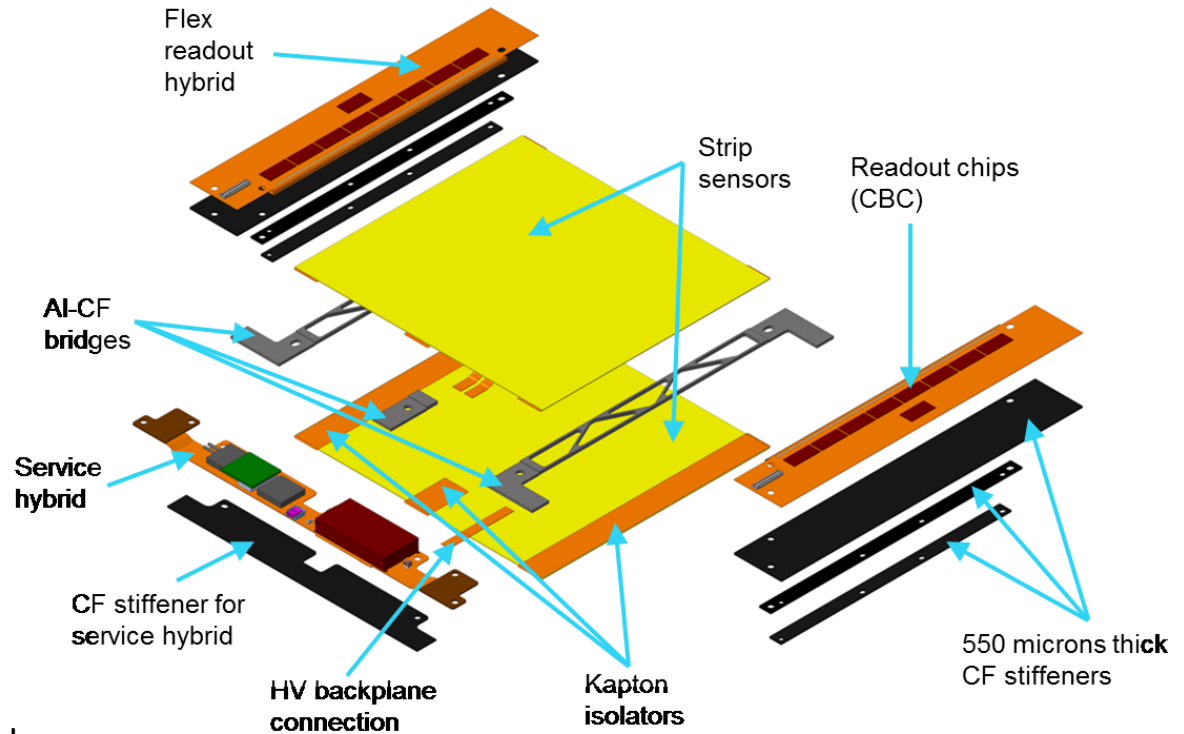
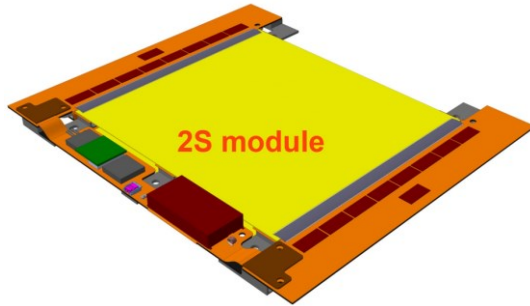


ATLAS ITk Strip Detector – Split Modules

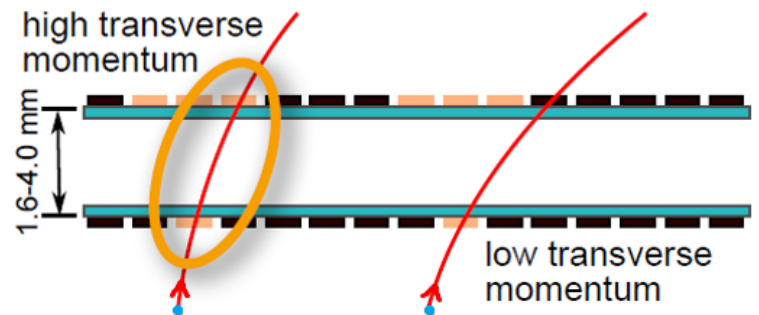
- Sensors for outer rings (R3, R4, R5) cannot be made from single silicon wafer
- Modules made from two sensors utilising split hybrids
- Remains basic architecture with data on LHS and power from RHS
- Split halves of modules are built separately
- Connections between split hybrids made by wire-bonding



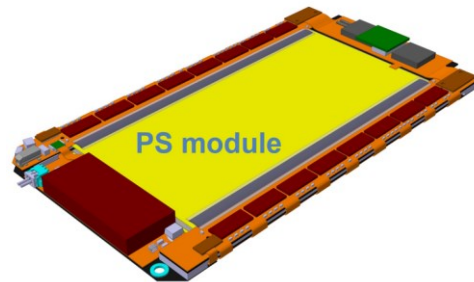
CMS Outer Tracker – 2S Modules



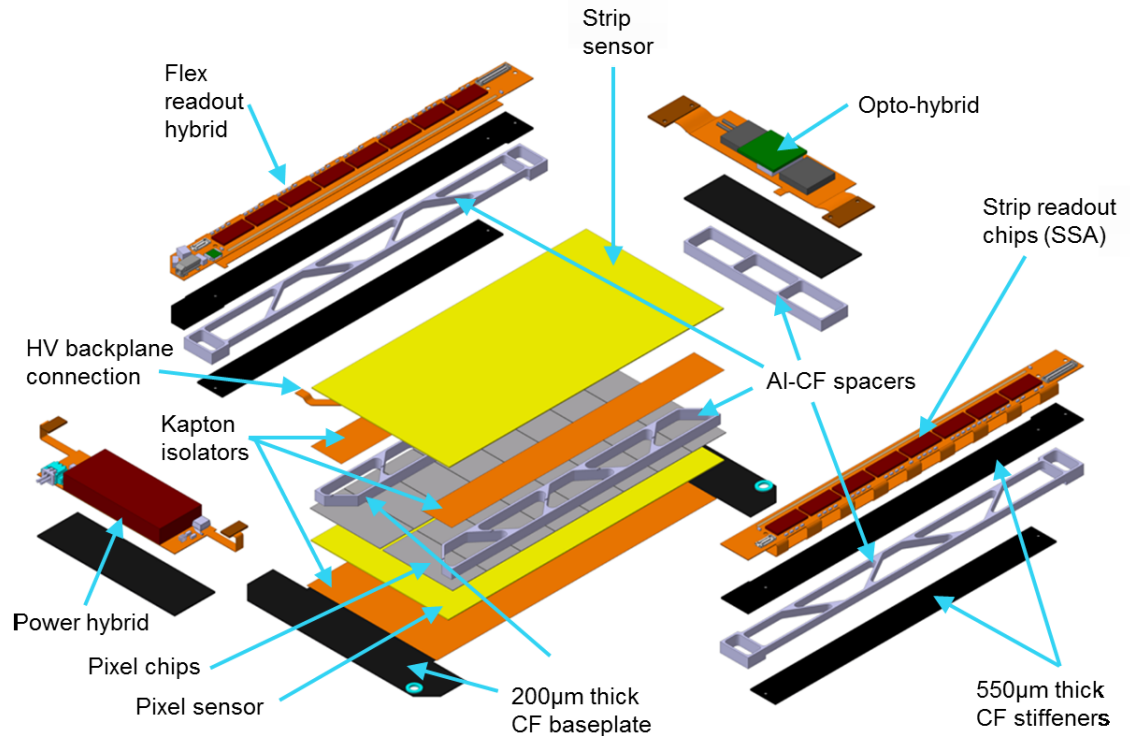
- 2 parallel 10x10 cm strip sensors
- CBC3 FE ASICs:
 - Reject low momentum tracks
 - Transmits stubs for every BC
 - Transmits strip data at L1A
- CIC ASIC:
 - Data concentrator chip
 - Forwards data to IpGBT



CMS Outer Tracker – PS Modules

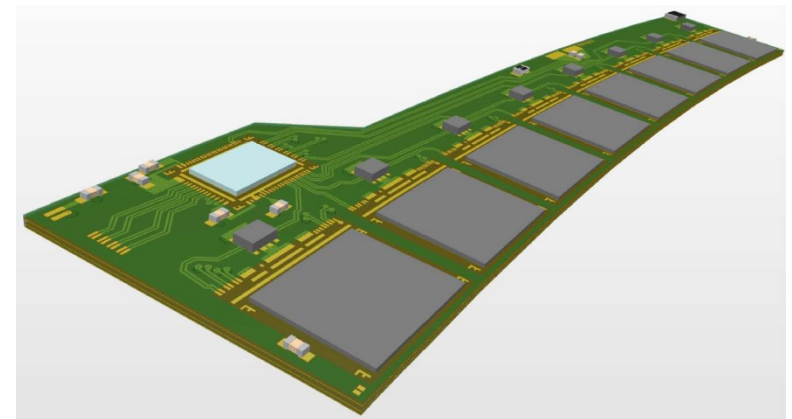
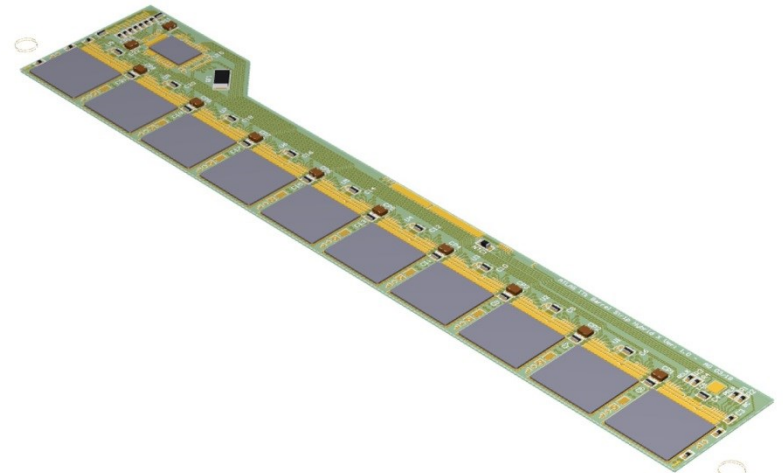
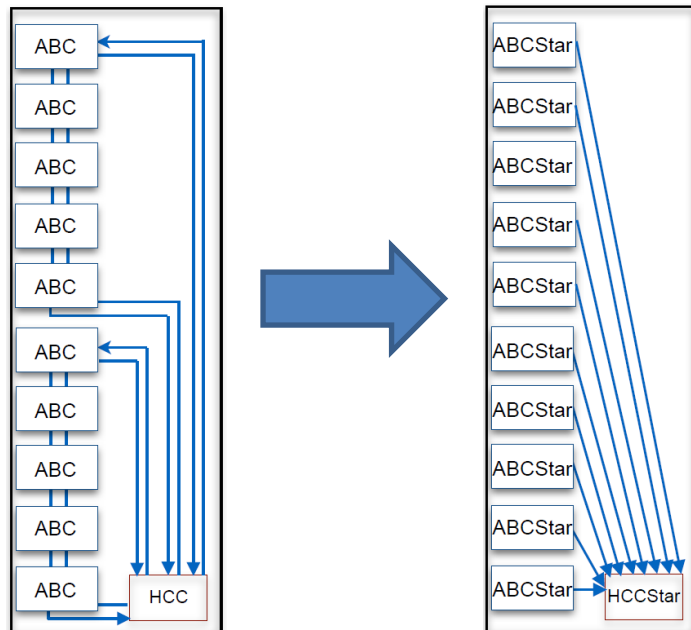


- 1 10x5cm strip sensor & 1 pixellated 10x5cm strip sensor
- SSA FE ASICs:
 - Transmits strip hits to pixel readout chip
- MPA FE ASICs:
 - Transmits stubs for every BC
- CIC ASIC:
 - Data concentrator chip
 - Forwards data to IpGBT

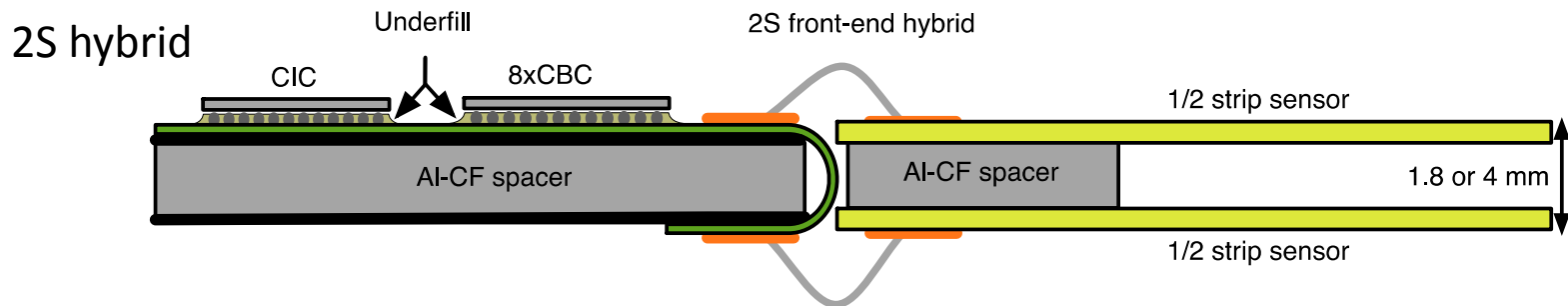


ATLAS ITk Strip Detector – Hybrids

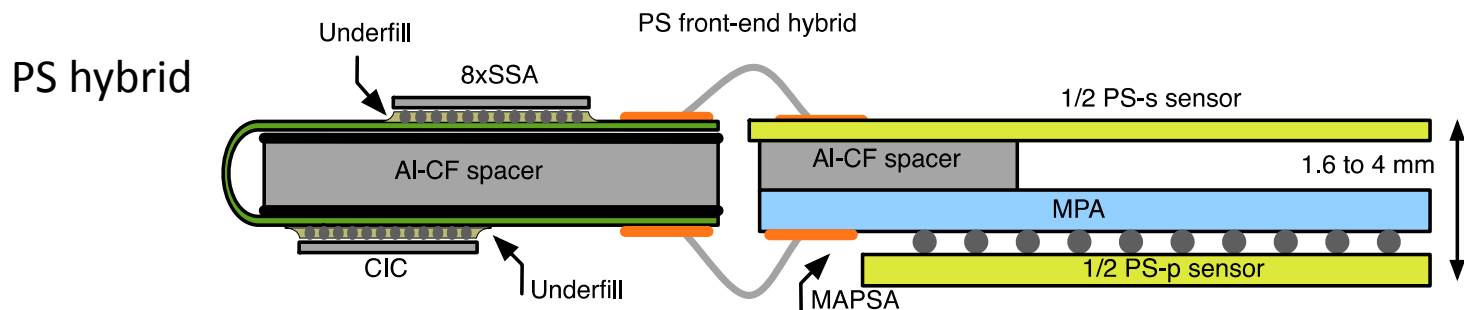
- Hybrid circuit comes as a 4 layer build
- Adheres to industry standard design rules for 100 μ m track-and-gap
 - Very portable between vendors
- ASICs glued down using UV cure epoxy
- For testing hybrids are wire-bonded to test frames
- Recently changed data flow architecture from “loop” to “star”



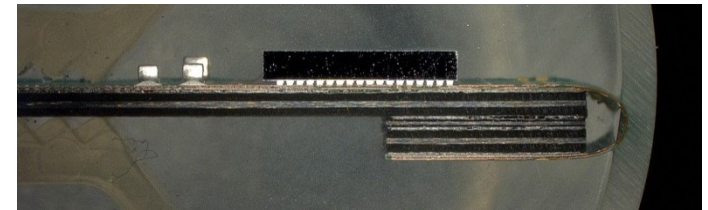
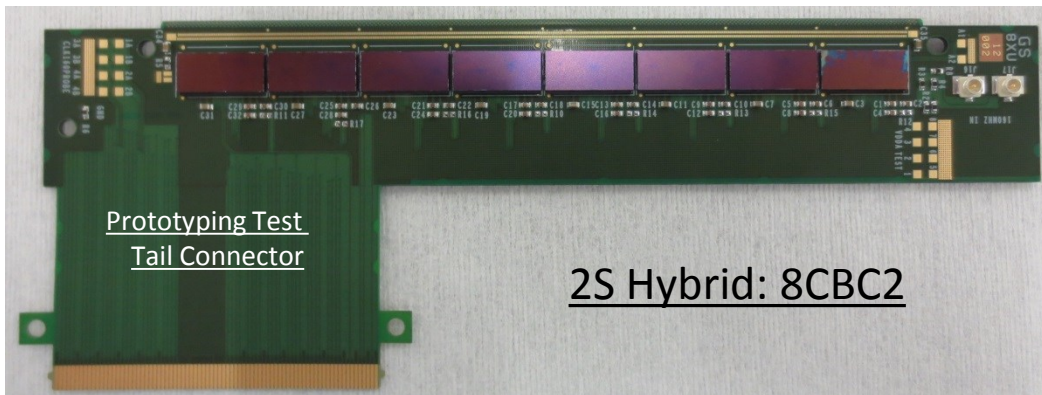
CMS Outer Tracker – Front-End Hybrids



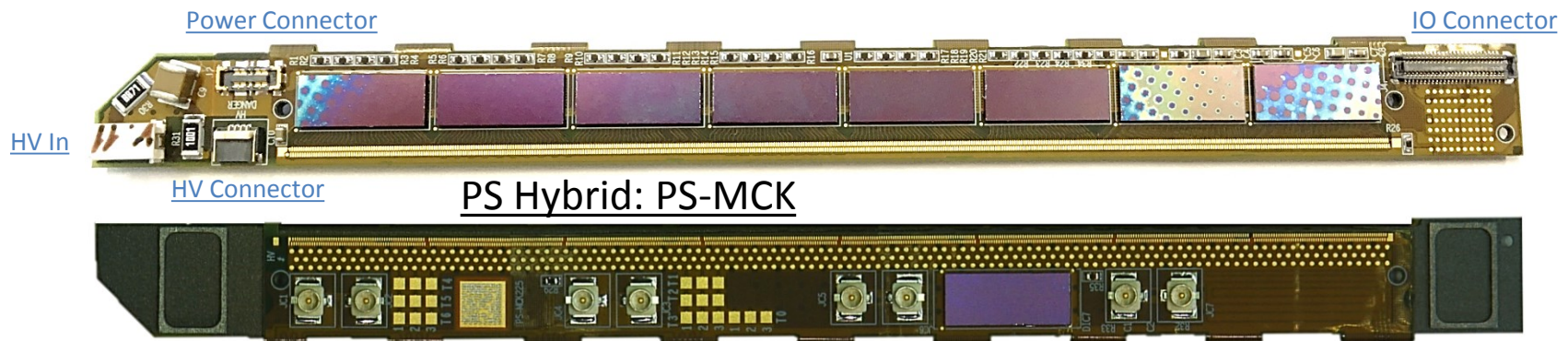
- 4 layer high density interconnecting flex circuits
- Flex is folded over a carbon fibre stiffener structure
 - 2S (folded): 20 x 125 mm
 - PS (folded): 10 x 125 mm
- ASICs are all flip-chipped to hybrids (250-270 μm pitch)
- Sensors wire-bonded to both top and bottom sides of hybrids
- MAPSA: pixellated strip sensor bump bonded to MPA readout ASICs and then wire-bonded to front-end hybrid



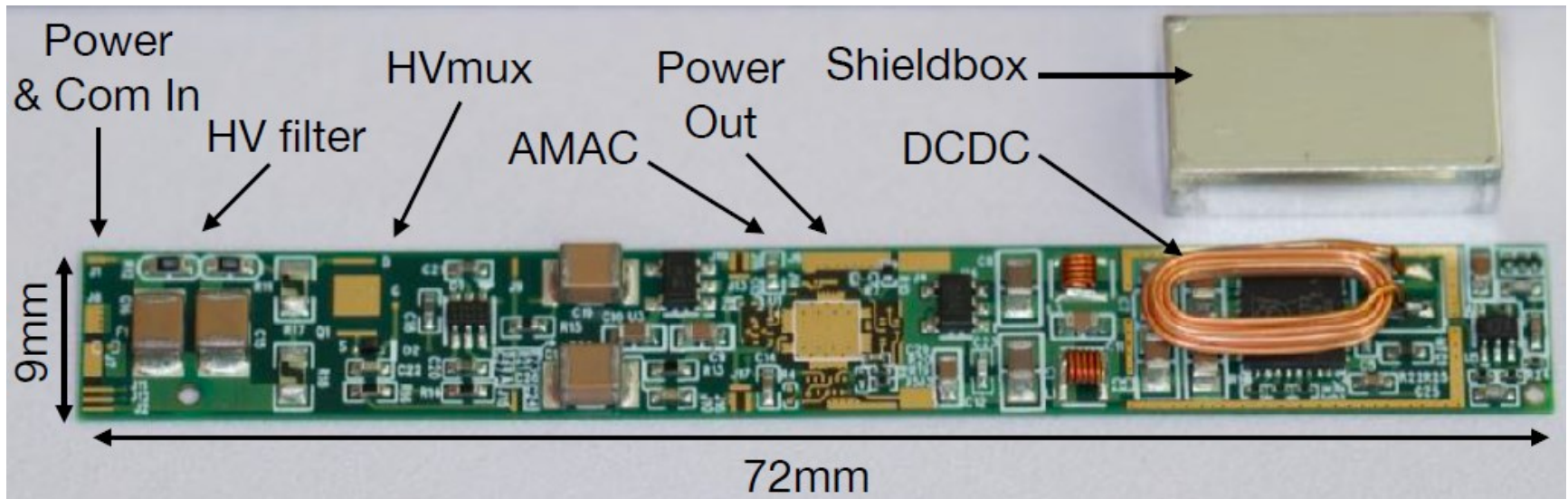
CMS Outer Tracker – Front-End Hybrids



- Several 2S hybrid prototypes built: 2CBC2, 8CBC2 (several batches), 2CBC3.
- Several contractors qualified for producing HDI flexes and assembling the hybrids.
- Test methods developed: functionality + contact-less identification of open-grounded-shorted inputs.
- Design constraints: laser vias ($25\ \mu\text{m}$), track width and spacing ($42.5\ \mu\text{m}/42.5\ \mu\text{m}$), 4 build-up layers.
- PS Hybrid demonstrator produced with all vendors: dummy ASICs but final geometry.



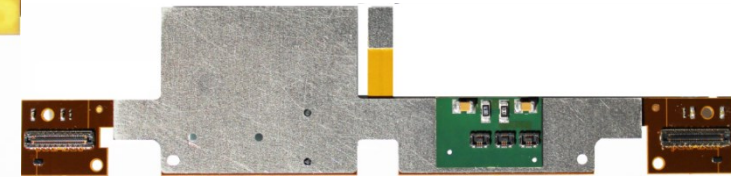
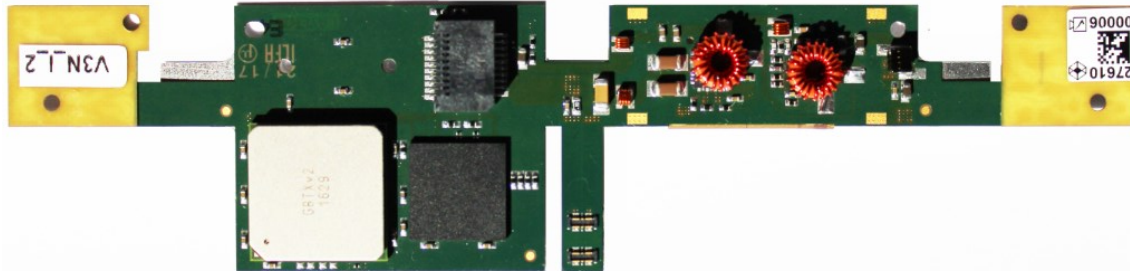
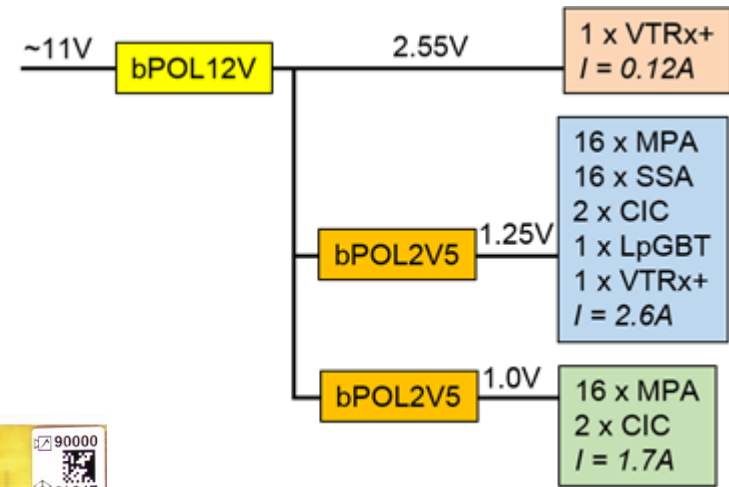
ATLAS ITk Strip Detector – Powerboard



- Powerboard is a separate circuit which provides power, control, monitoring and interlocking to the module
- Includes:
 - DC-DC converter (11V in, 1V5 out) currently based on Feast 2.1, eventually BPOL12V
 - Low profile, 5mm high, 100 μm thick Al shieldbox
 - Custom solenoidal coil due to clearance requirements
 - Autonomous Monitoring And Control (AMAC) ASIC for monitoring, control and autonomous interlocking
 - Linear regulator (11Vin, 1V5 out) currently using commercial parts, eventually LINPOL12V
 - HV control based on GaNFET switch

CMS Outer Tracker – Service Hybrids

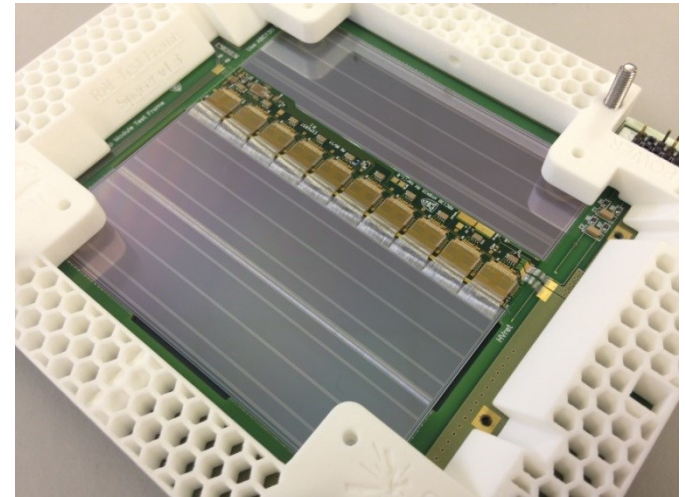
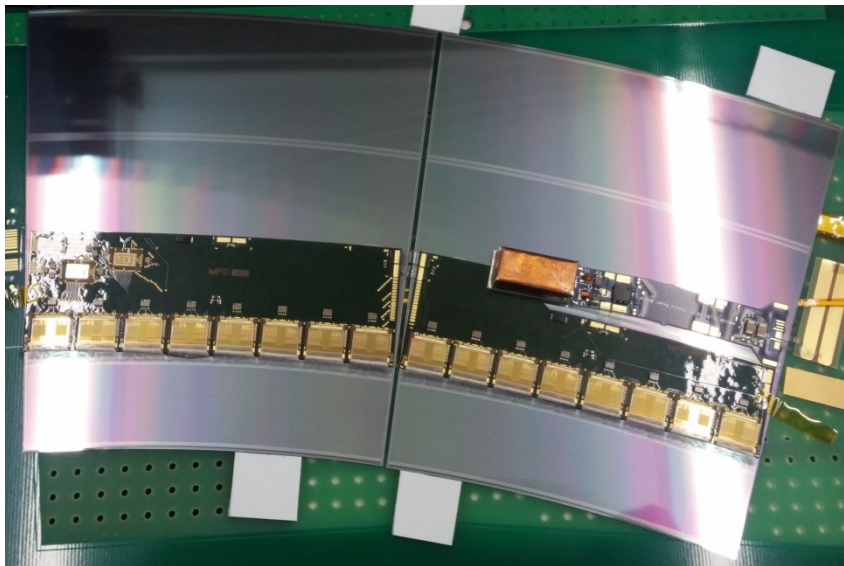
- Provides low (2.55V, 1.25V, 1.0V) and high voltage, data aggregation, opto-electrical conversion
- 2-step DC-DC conversion powering scheme
 - bPOL12V & bPOL2V5 buck converters (CERN)
- LpGBT (CERN) aggregates data from CIC
- Implements slow control functionality
- Opto-electrical converter (VTRx+, CERN)
- All chips are still under development
- 2S prototypes made, using predecessors (GBTx, FEAST2.1, VTRx) and COTS active components



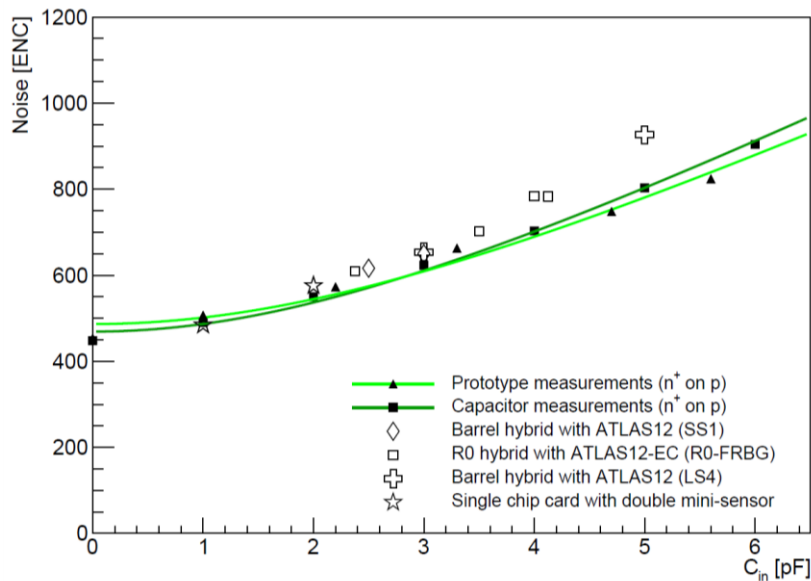
ATLAS ITk Strip Detector – Prototypes

Currently have prototypes based on ABC130/HCC130 chipset

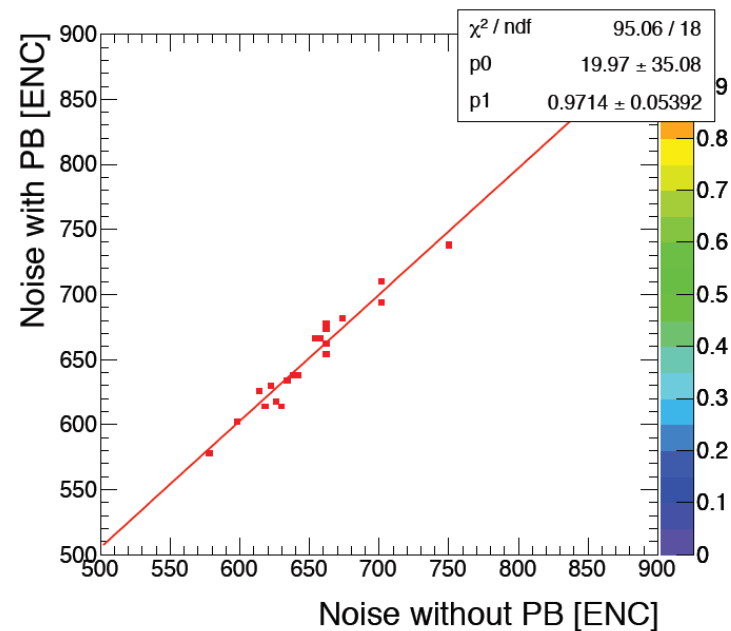
- Short strip modules including powerboards with AMAC monitoring and control
- Long strip modules made from short strip sensors with wire-bonding to gang strips together
- R0 modules including powerboards
- R4/R5 prototypes demonstrating the split module concept



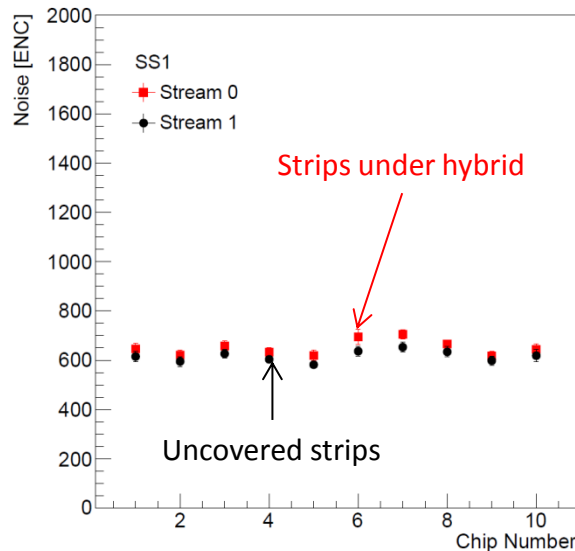
ATLAS ITk Strip Detector – Prototypes



Benchtop testing shows good agreement between prototype FE measurements and results on modules

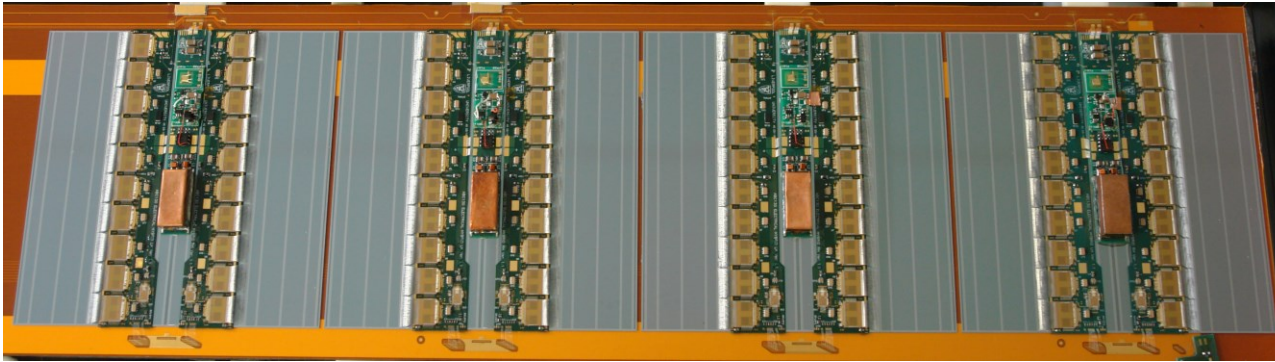


Chip-by-chip variation on a module

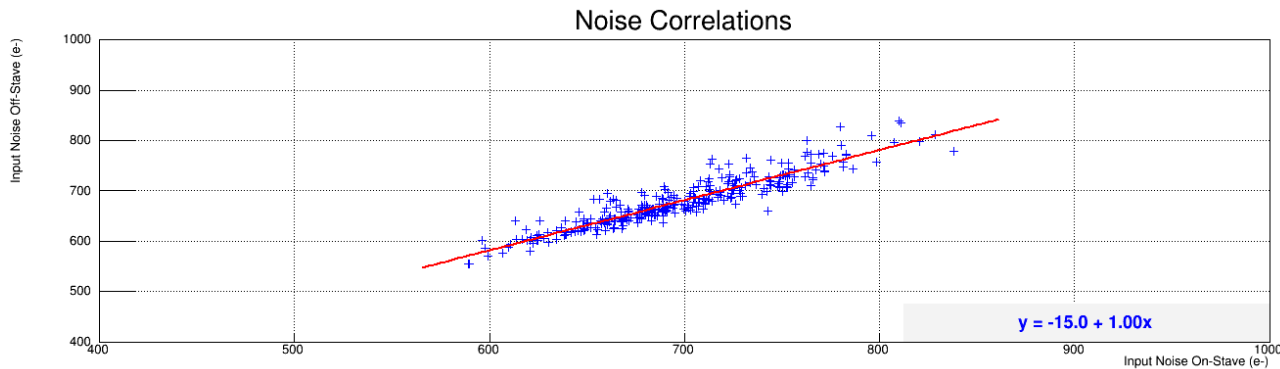


Attachment of powerboard directly to silicon sensor surface shows very little change in module noise performance

ATLAS ITk Strip Detector – Prototypes

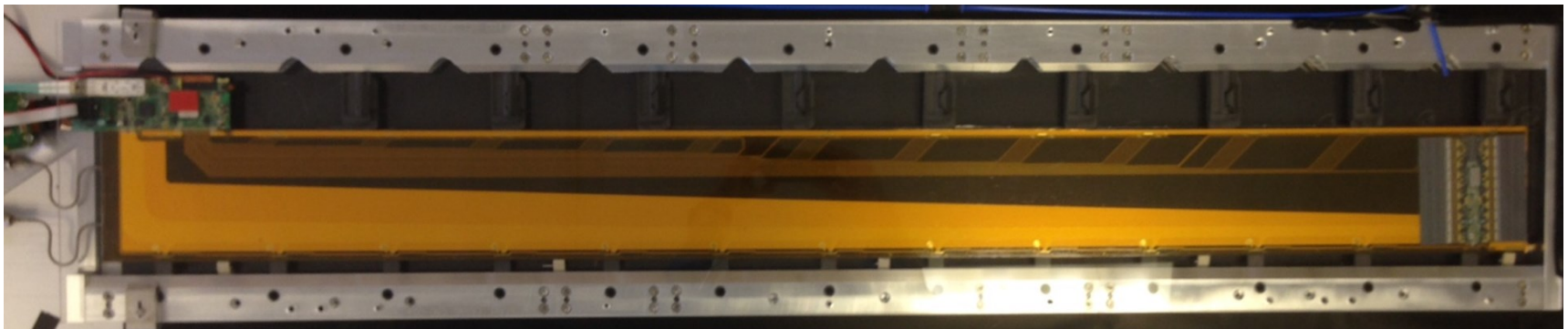


Prototype short strip modules on stave



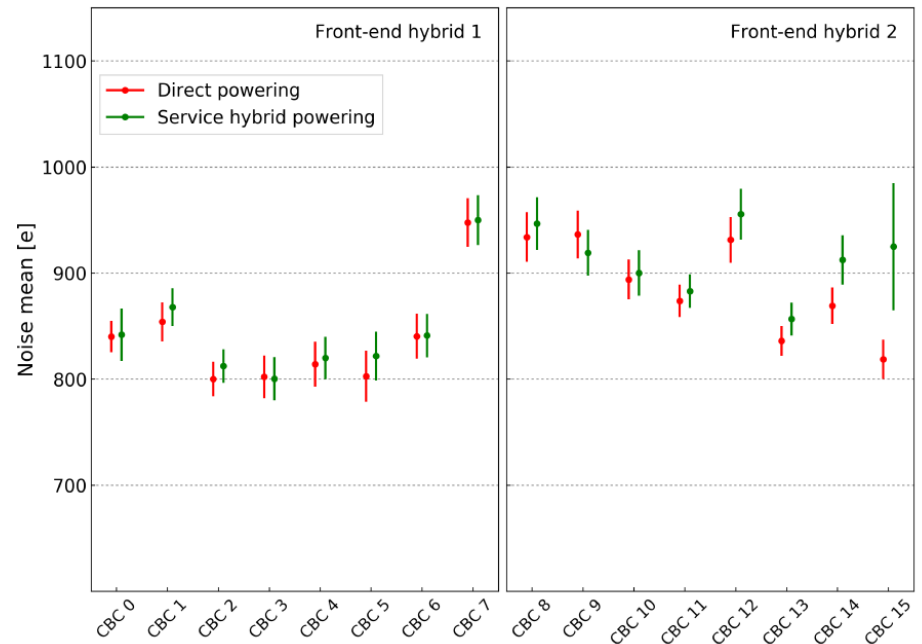
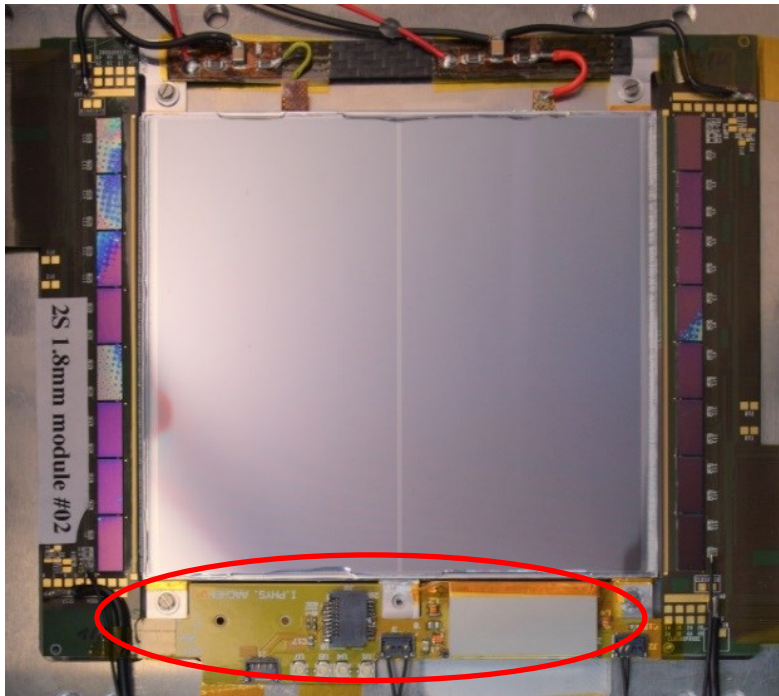
4 module prototype with electrical readout

Single module prototype with optical readout via GBTx



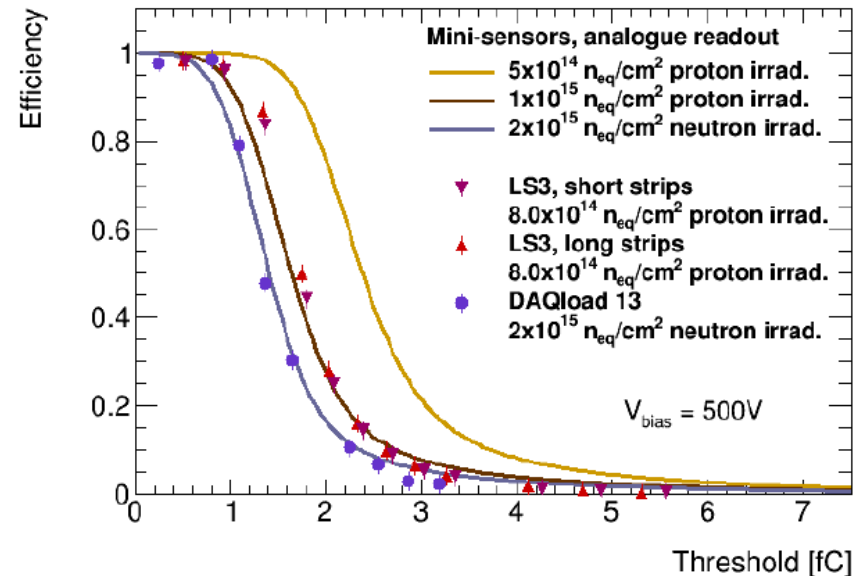
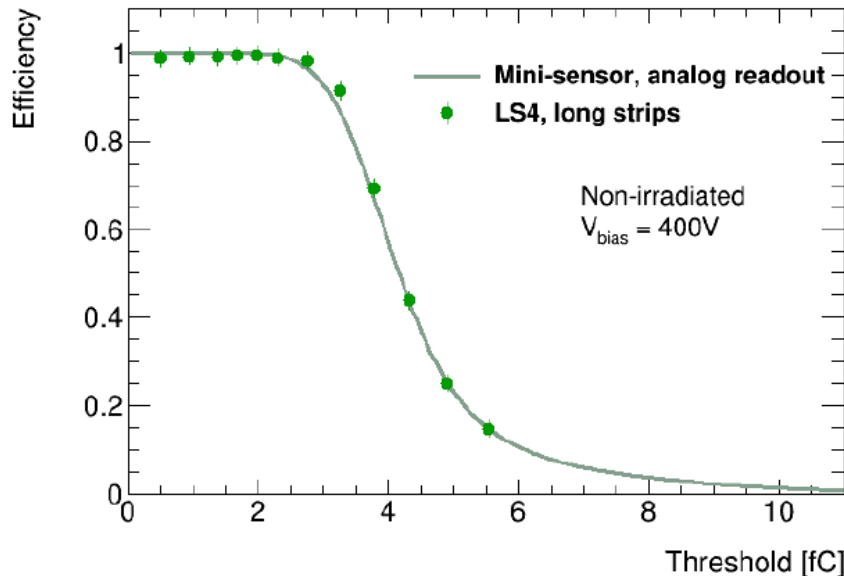
CMS Outer Tracker – Prototypes

- Feasibility of 2-step DC-DC scheme demonstrated
- Noise interference studied using prototype service hybrids with DC-DC converters to power a **full 2S module prototype**
- Noise within specification (1000e) for all readout chips
- Studies of signal integrity and readout via Service Hybrid ongoing



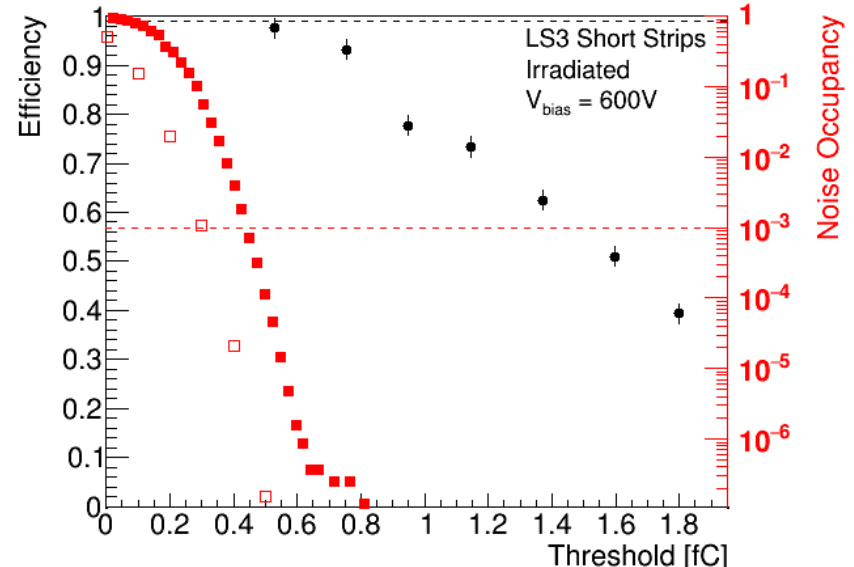
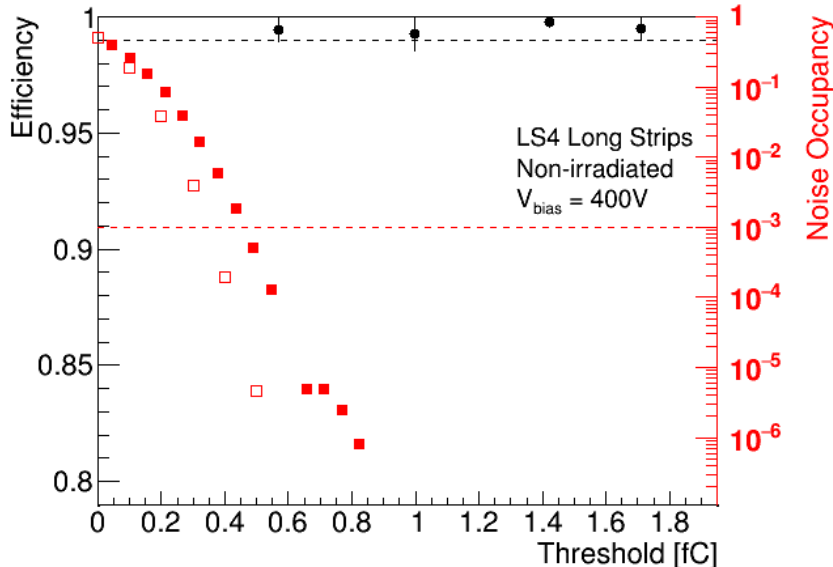
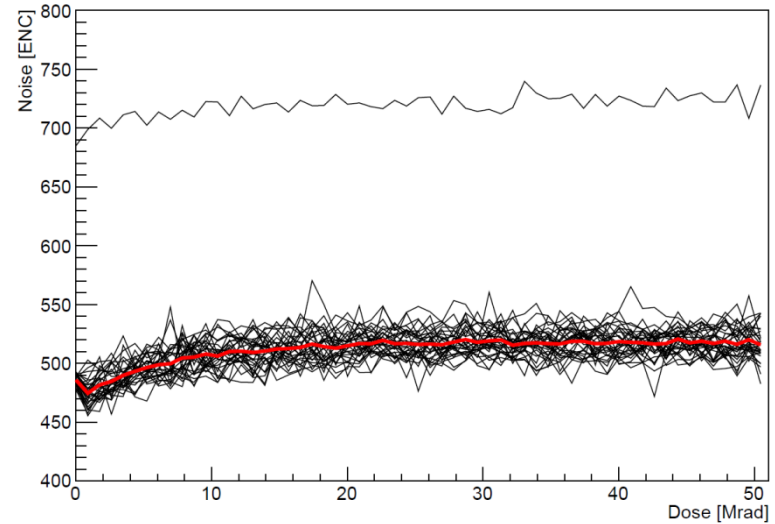
ATLAS ITk Strip Detector – Testbeam

- Testbeam measurements on full modules before and after irradiation
- Compared to analogue readout measurements from sensor studies

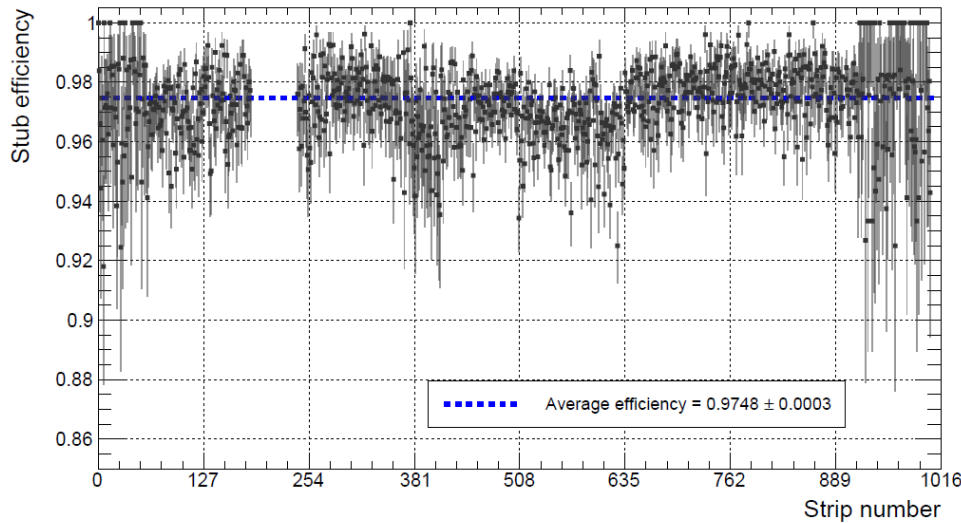


ATLAS ITk Strip Detector - Testbeam

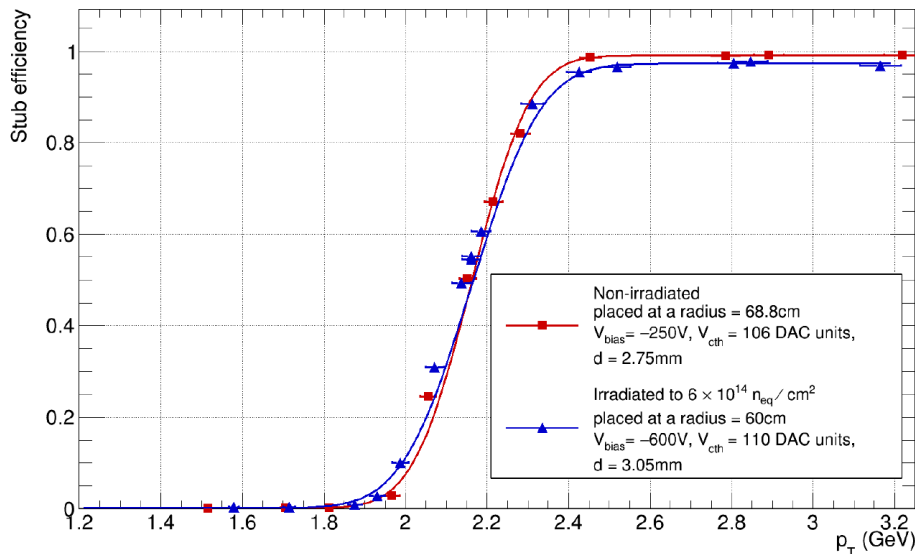
- Barrel module performance evaluated before and after irradiation
- Modules required to have:
 1. 99% detection efficiency
 2. Less than 10^{-3} noise occupancy
- Clear operating window before irradiation
- After irradiation small operating window but expected to be improved with new FE in ABCStar (analogue stages already prototyped)



CMS Outer Tracker – Testbeam



- Stub identification efficiency of 2S modules tested at testbeam
- 97% average efficiency across full width of module
- Good agreement between stub identification efficiency before and after irradiation



ATLAS ITk Strip Detector – Coming Soon...

- **ASICs**
 - ABCStar/HCCStar expected back in Q3 2018
 - AMACv2 expected back in Q2 2018
 - Availability of ASICs will enable fabrication of all hybrids
- **Sensors**
 - Close-to-final long-strip sensors arriving through 2018
- **Hybrids**
 - First Starchip hybrid designs almost complete
 - First hybrids back in time for ABCStar/HCCStar
 - First Starchip hybrids and modules by the end of 2018
- **Powerboard**
 - Design of final powerboard version (using AMACv2) well advanced
 - LINPOL12V available summer 2018
 - Prototypes will use Feast 2.1 until BPOL12V available

CMS Outer Tracker – Coming Soon...

- **Qualification of ASICs**
 - CBC3 validated, minor interation for CBC3.1 due by Q3 2018.
 - SSA and MPA chips are being qualified now.
 - CIC design being completed now, ASIC expected Q4 2018.
 - Availability of ASICs will enable fabrication of all hybrids variants.
- **Front-end hybrids and designs**
 - 8 CBC3 in fabrication: first final 2S hybrid (no CIC yet).
 - All 2S hybrid designs due by end 2018 (left and right sides, all spacings, with CIC) for qualification in 2019.
 - All PS hybrid designs due by end 2018 (left and right sides, all spacings, with CIC) for qualification in 2019.
- **Service Hybrids**
 - PS Power Hybrid under development
- **Testing infrastructure**
 - Production scale test system for PS front-end hybrids under development all 2018.
 - Production scale test system for 2S front-end hybrids by 2019.
 - Prototype test system for Service Hybrids developed and under commissioning

Conclusions

- Have shown the outer tracker concepts currently being developed for Phase-II upgrades of CMS and ATLAS
- Hybrid, powerboard/service hybrid and module prototyping has continued since the submission of the TDRs in 2017
- New chips and new hybrids expected to appear throughout 2018 and into 2019
- Although not shown today, both collaborations have well developed assembly methods in place
- Exciting times ahead!

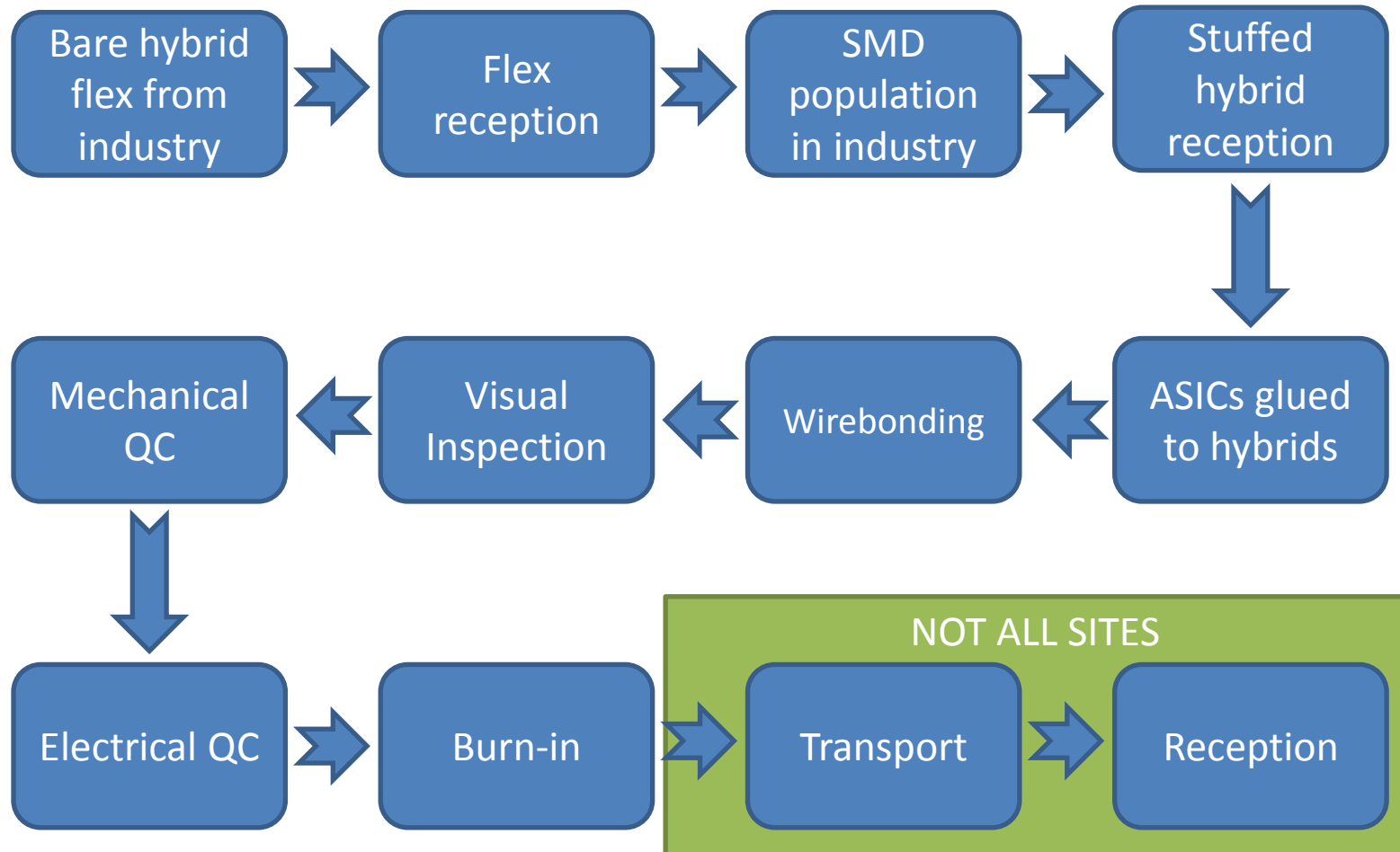


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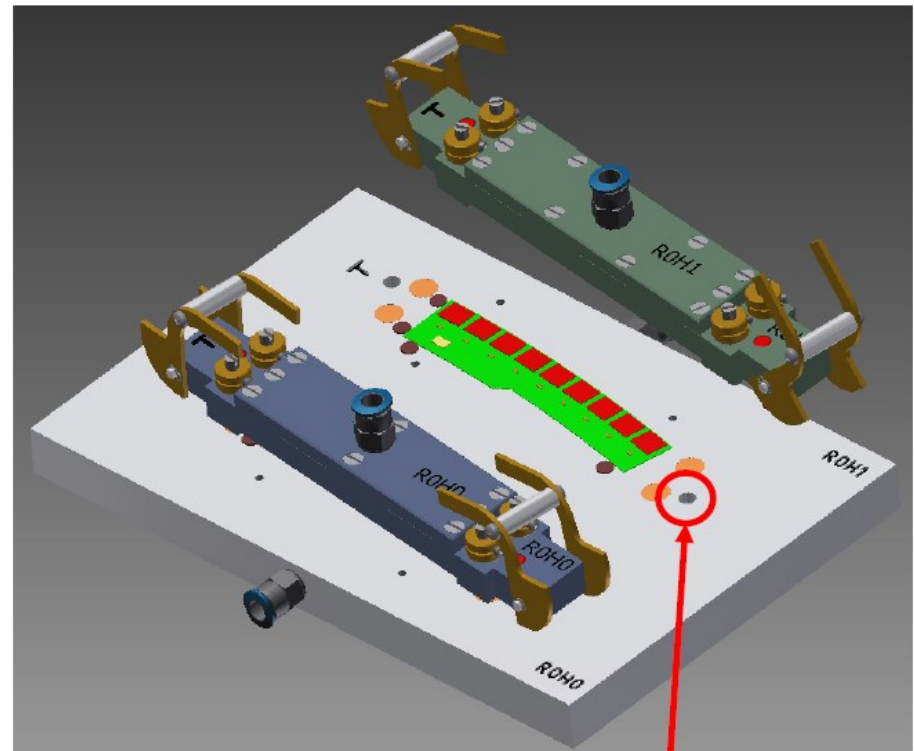
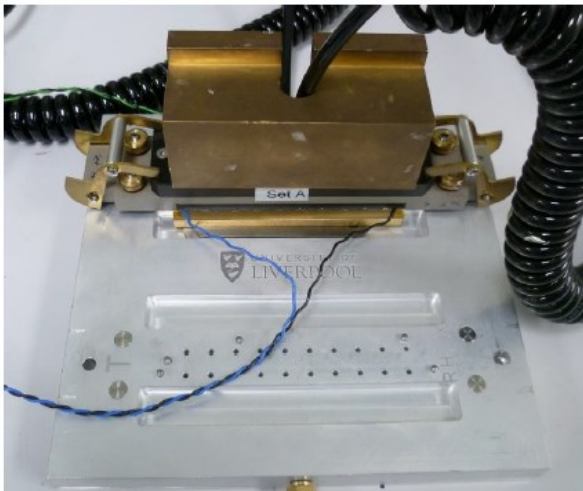
BACK-UP

ATLAS ITk Strip Detector – Hybrid Assembly



ATLAS ITk Strip Detector – Hybrid Assembly

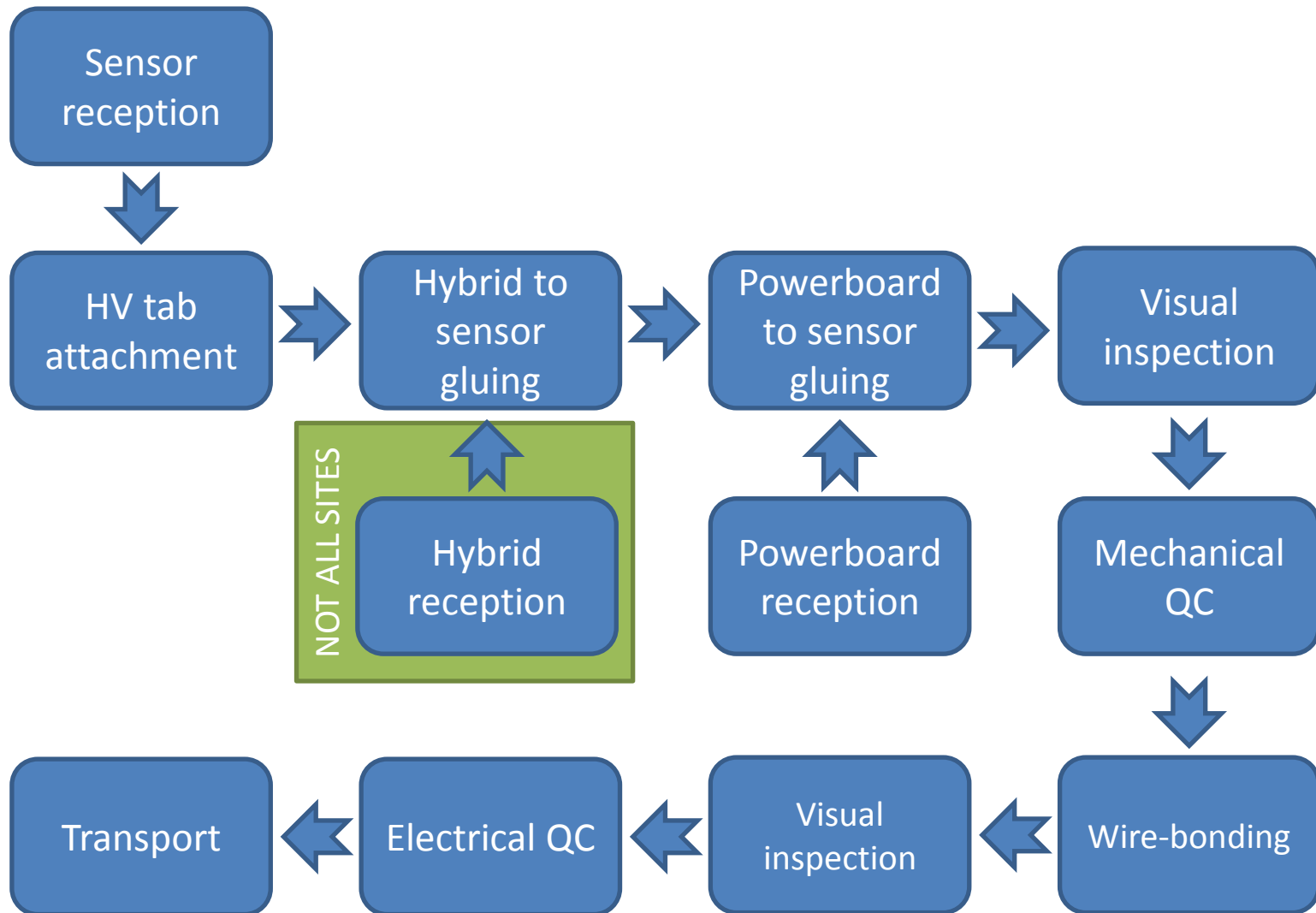
- ASICs placed on hybrid in jig
- Dowel holes in jig for precision placement
- Weight on pick-up tool during curing process
- UV glue cured in jig for several minutes



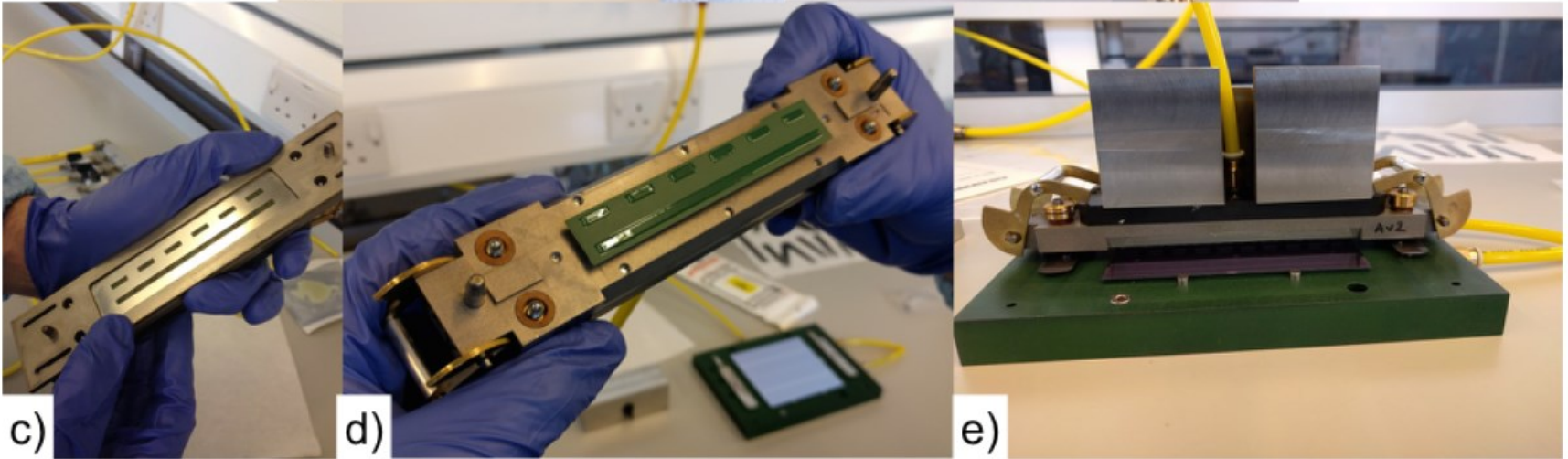
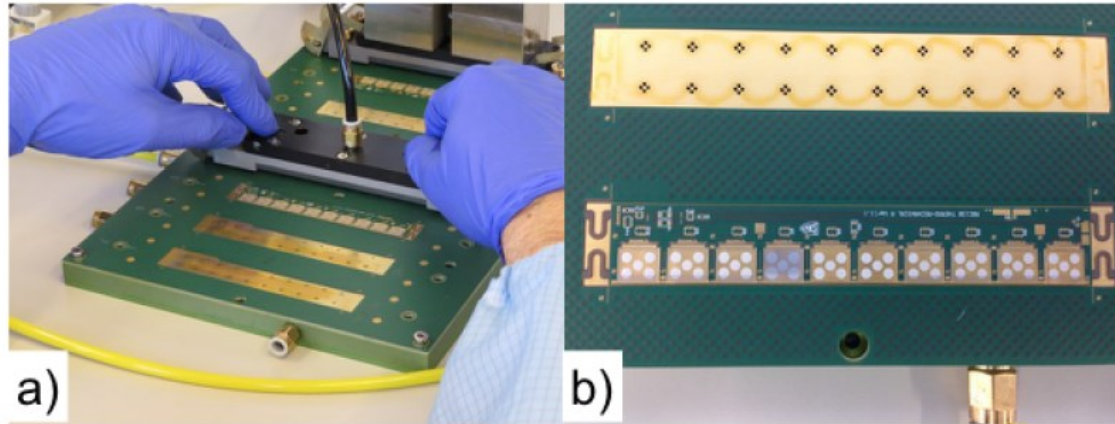
Alignment holes



ATLAS ITk Strip Detector – Module Assembly



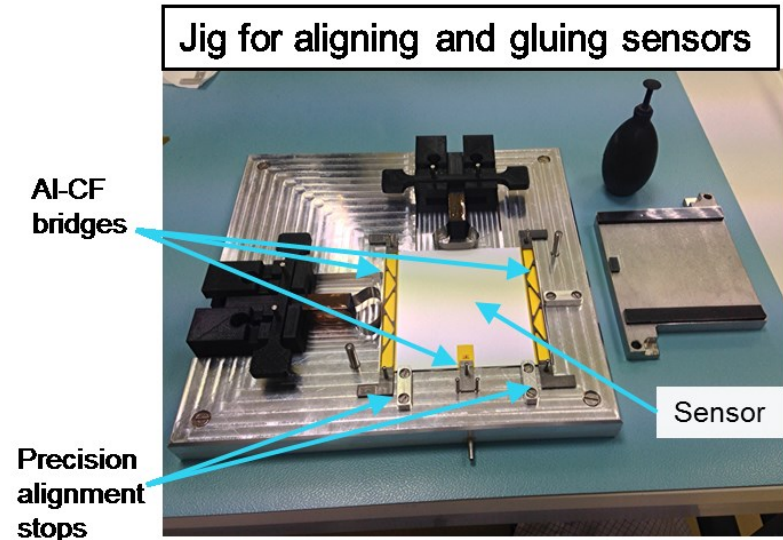
ATLAS ITk Strip Detector – Module Assembly



CMS Outer Tracker – 2S Module Assembly

Basic steps in 2S module assembly

- Preparation of sensors, Kapton isolators and HV backplane bias circuit
- Gluing of isolators and bias circuit to backplane of sensors
- Gluing of Al-CF bridges to isolators on sensors (both sensors at once)
- Gluing of readout and service hybrids to Al-CF bridge supports
- Wire bonding of sensors to readout hybrids
- Electrical test
- Wire bond encapsulation
- Final electrical test



Functional 2S 1.8mm prototype module

