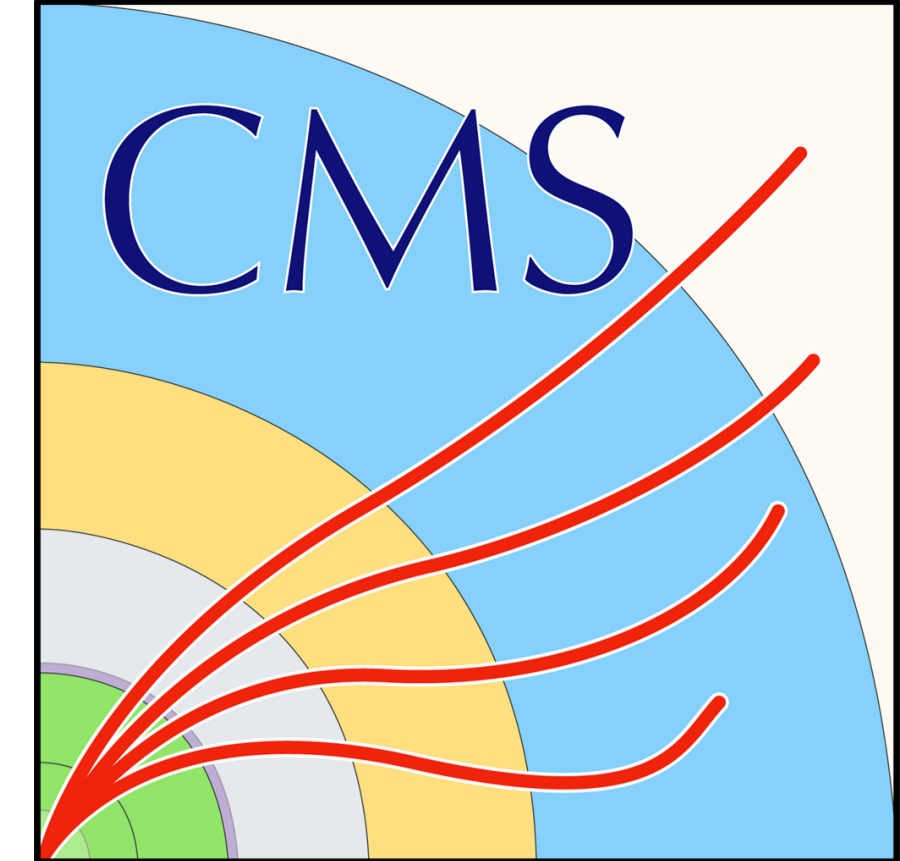


Quality inspection aspects of hybrid prototypes for the CMS Outer Tracker upgrade at HL-LHC



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Abstract:

In the HL-LHC scenario, the CMS experiment will need to operate at up to 200 interactions per 25 ns beam crossing time and with up to 4000 fb⁻¹ of integrated luminosity. To achieve the physics goals the experiment needs to improve the tracking resolution and the ability to selectively trigger on specific physics events. The CMS Tracker upgrade requires designing a new detector to cope with HL-LHC scenario. The new Outer Tracker (OT) is based on two silicon modules (strip-strip and pixel-strip). Each module type has a few types of high-density interconnect hybrid circuits which house the front-end and auxiliary electronics. Two sides of the sensors are wire-bonded to the front-end hybrids. For both module types, folded flexible circuits are used to enable wire-bonded connection from the sensor assemblies with various spacing. The poster introduces the technological choices for modules and hybrids and presents the quality inspection aspects of the first hybrid prototypes.

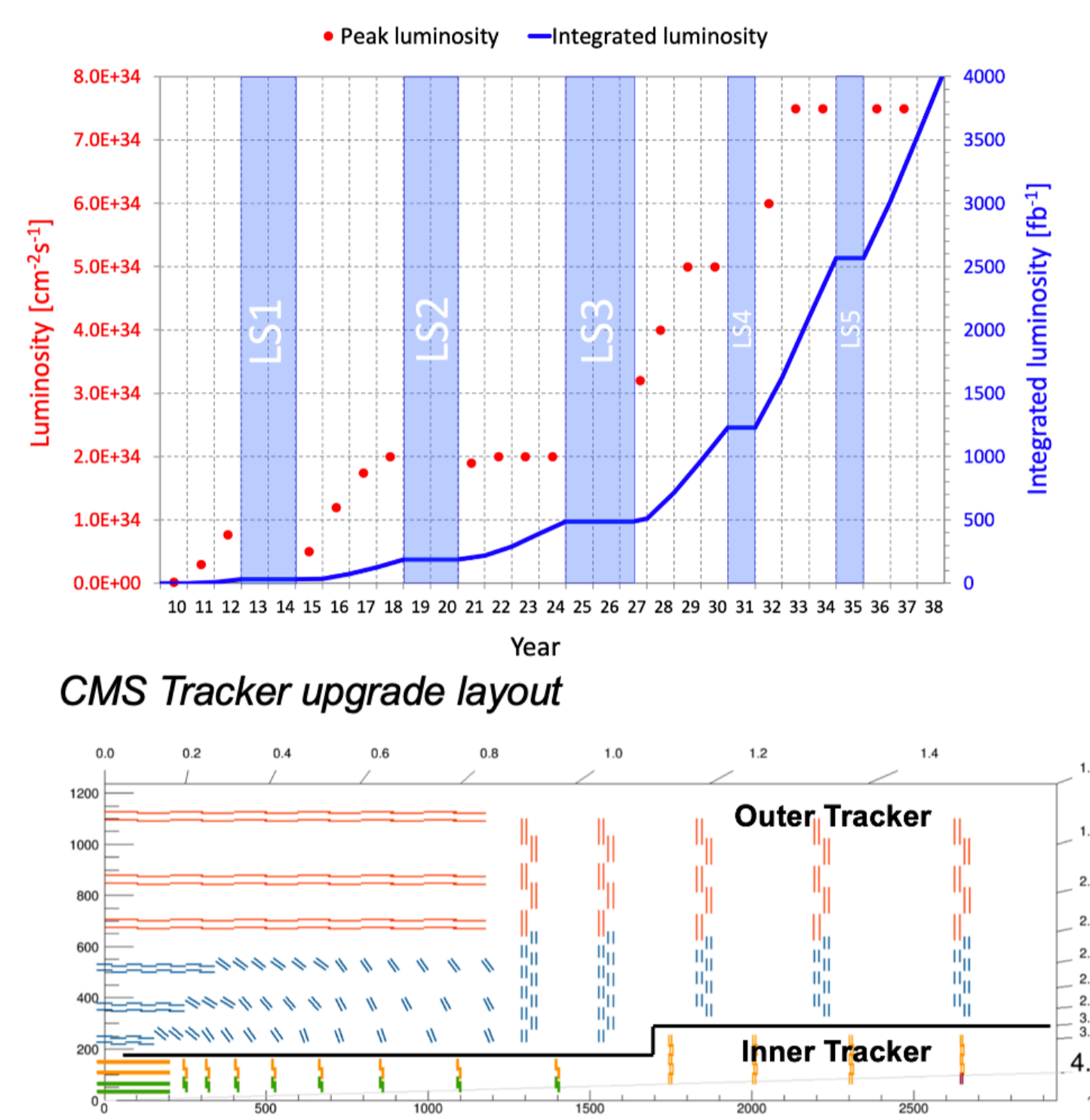
Motivation and requirements

High Luminosity LHC upgrade:

- Increase of pile-up to ~200
- Peak Luminosity ~7.5x10³⁴ cm⁻² s⁻¹
- Integrated luminosity of ~4000 fb⁻¹

CMS Tracker upgrade key features:

- High granularity to keep channels occupancy low
- Radiation hardness (fluence & total ionizing dose):
 - Innermost layers: 2.3 x 10¹⁶ n_{eq} cm⁻² & 1.2 Grad
 - Outer layers: 10¹⁵ n_{eq} cm⁻² & 100 Mrad
- Low material budget for improving tracking performance in high pile-up scenario
- Contribute to trigger level 1 by using transverse momentum of tracks to reduce data volume



Tracker input to the Level 1 trigger

The use of tracking information in L1 trigger implies that:

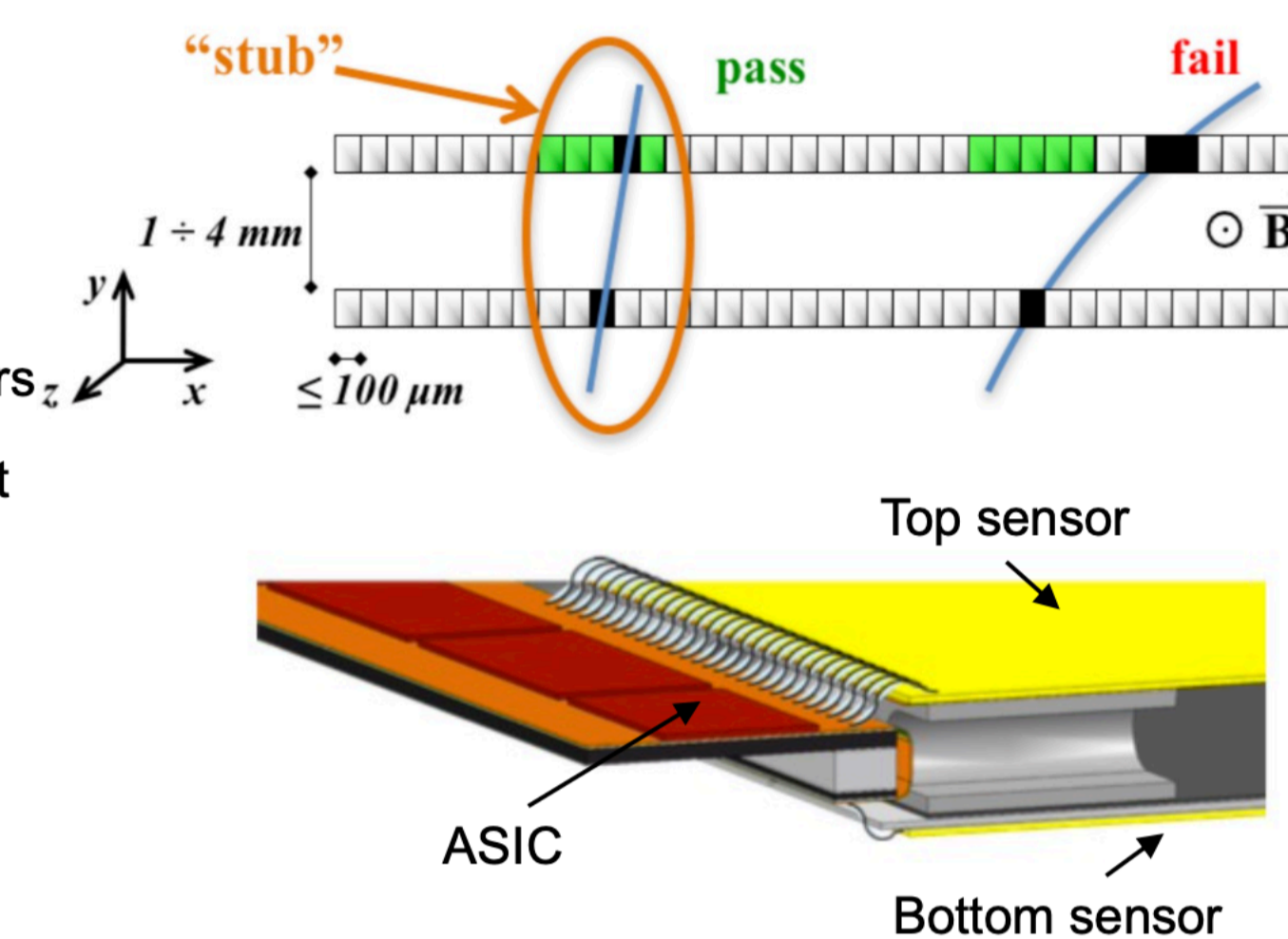
- The tracker has to send out self-selected information at every bunch crossing
- Local data reduction is needed in the ASIC to limit the volume of data that has to be sent out at 40MHz

Charged particles are bent in CMS's 3.8T magnetic field with bending angle depending on their p_T

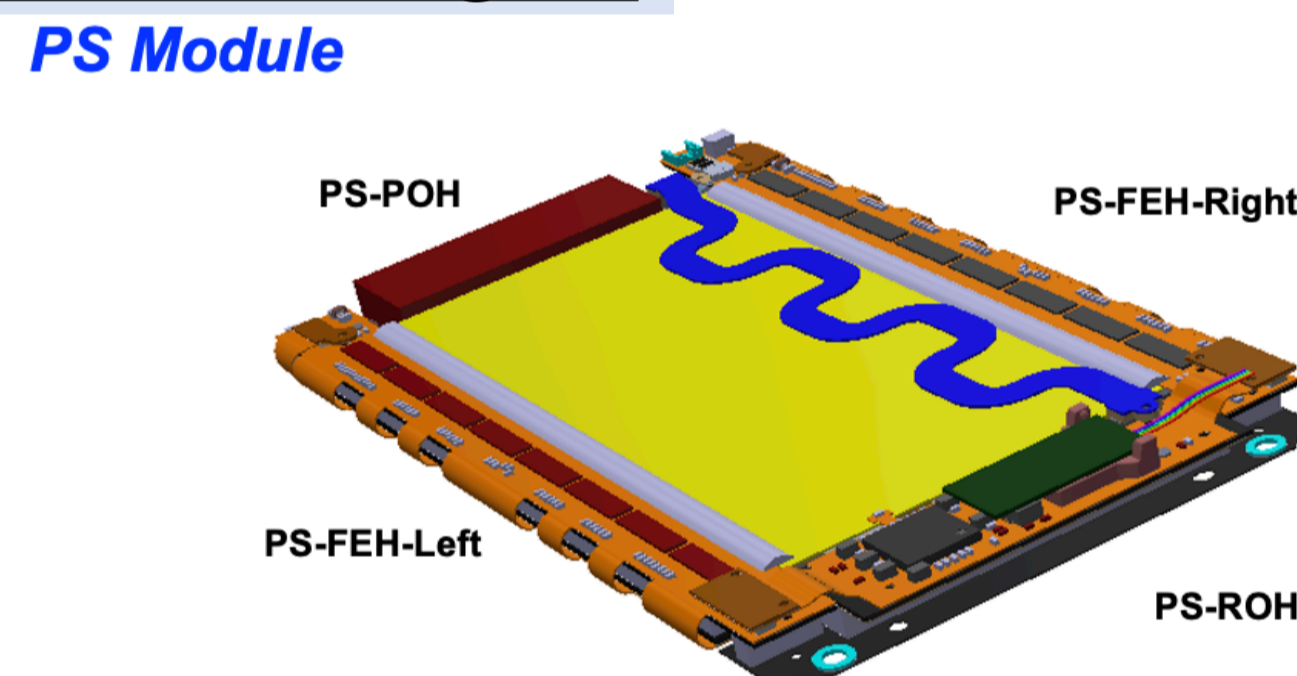
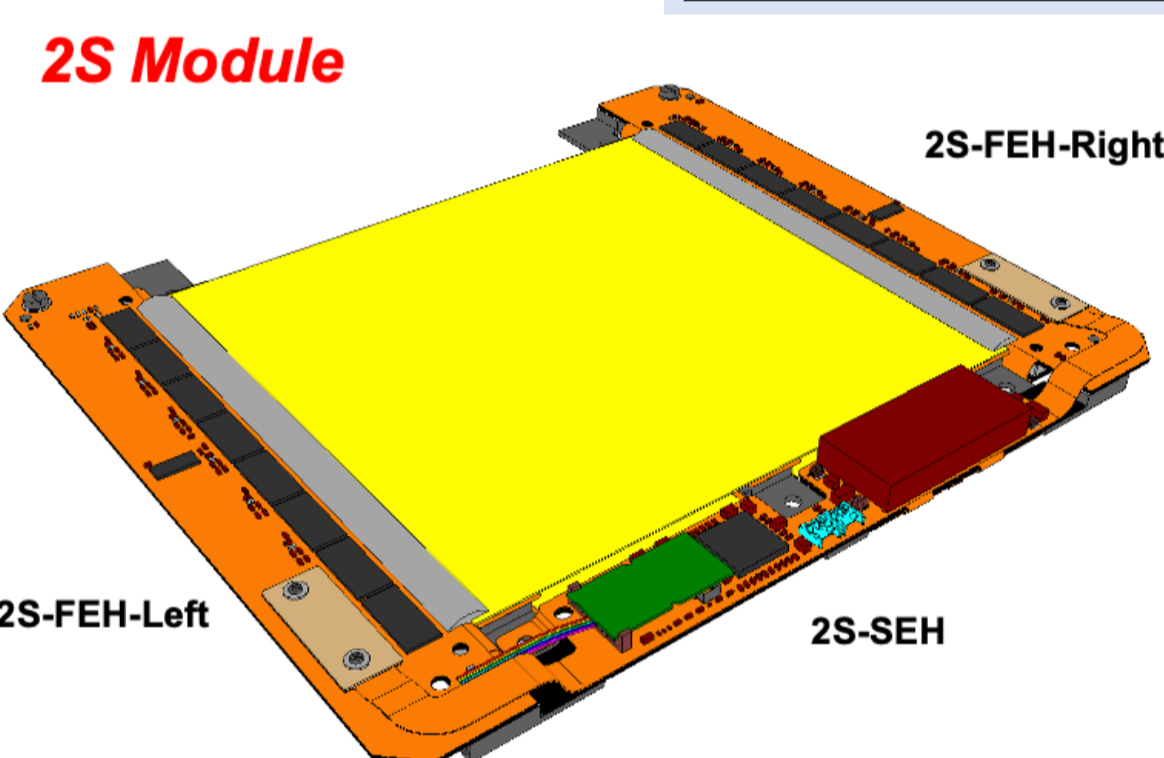
- Modules need to be capable of rejecting signals from particles below a certain p_T threshold

- Module concept:

- Two silicon sensors with a small spacing between sensors
- One ASIC correlates data from both sensors selecting hit pair (stub) compatible with a chosen p_T threshold
- p_T threshold depends on acceptance window tunable by programming settings in the ASIC
- Different sensors spacing are optimized to enable homogeneous p_T (>2GeV/c) filtering in different detector regions



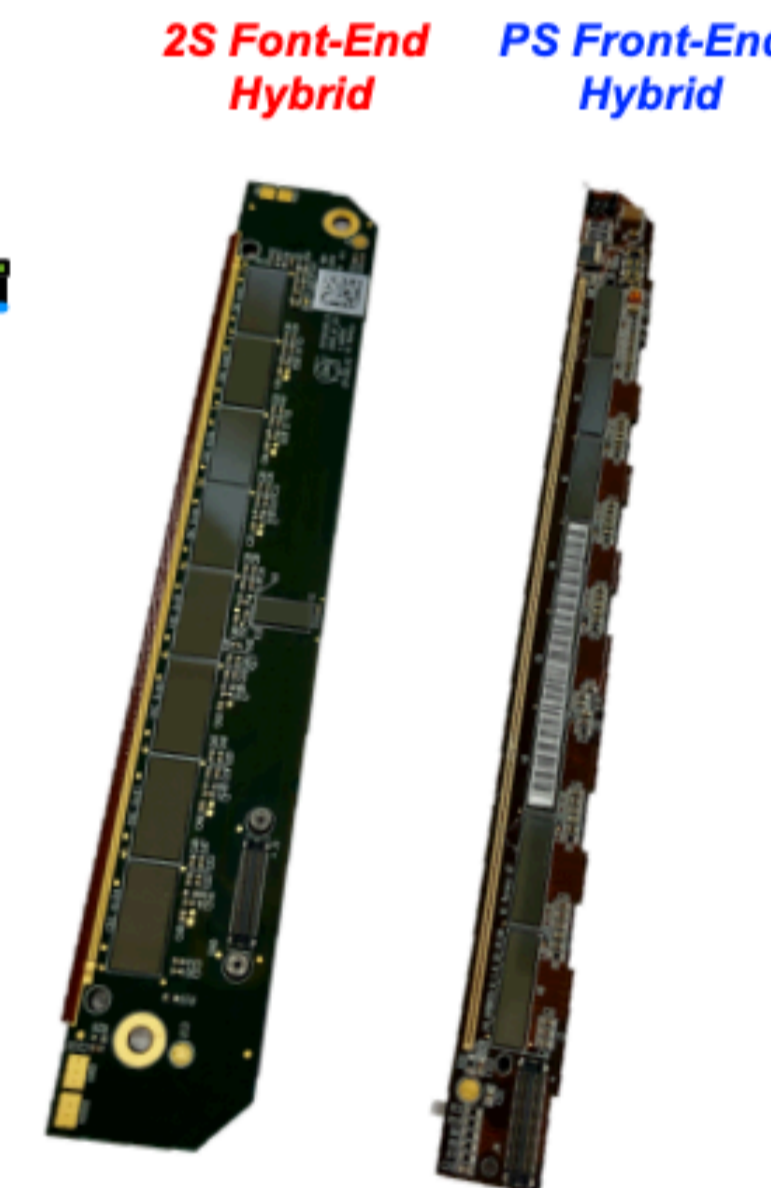
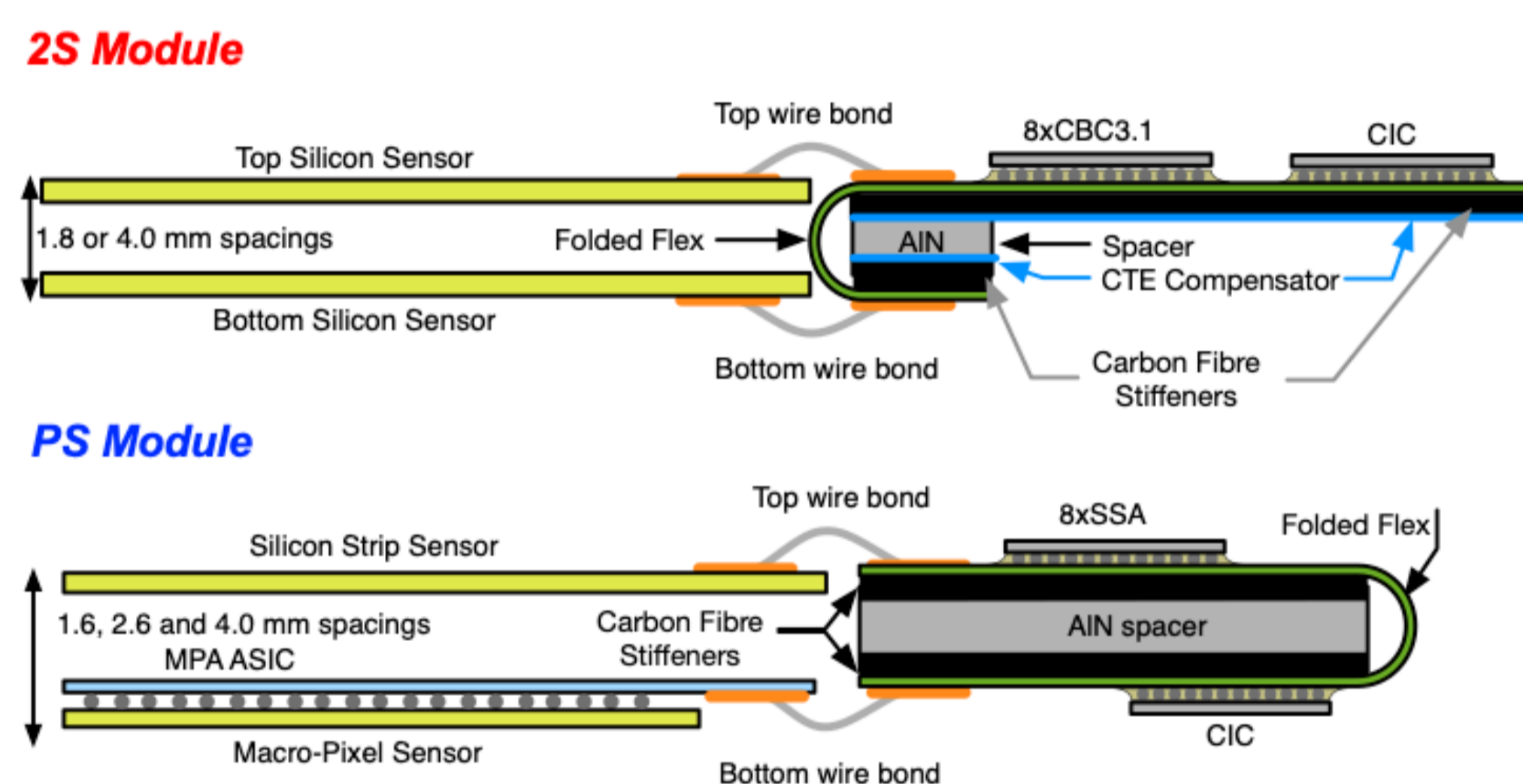
Outer Tracker module designs



- **Two parallel silicon strip sensors**
 - 2 x 1016 strips, 90 μm pitch
 - 90 cm² active area
- **Left and Right side 2S-FEH front-end hybrids**
 - Based on bump bonded CBC3.1(*) chips and CIC(*) chip
- **One 2S-SEH service hybrid containing**
 - DCDC(*) converters based on BPOL(*) chips
 - Optical readout based on the IpGBT(*) and the VTRx+ (*)
- **Silicon strip and macro-pixel sensors**
 - 2 x 960 strips, 100 μm pitch
 - 32 x 960 macro-pixels, 1.5 mm x 100 μm
 - 45 cm² active area
- **Left and Right sides PS-FEH front-end hybrids**
 - Based on bump bonded SSA(*) and CIC chips, wire bonded to MaPSA(*) array
- **Two service hybrids**
 - PS-POH Power Hybrid based on BPOL chips
 - PS-ROH Readout Hybrid based on the IpGBT and the VTRx+

* The Phase-2 Upgrade of the CMS Tracker – Technical Design Report, CERN-LHCC- 2017-009, CMS-TDR-014.

Front-End Hybrids topologies



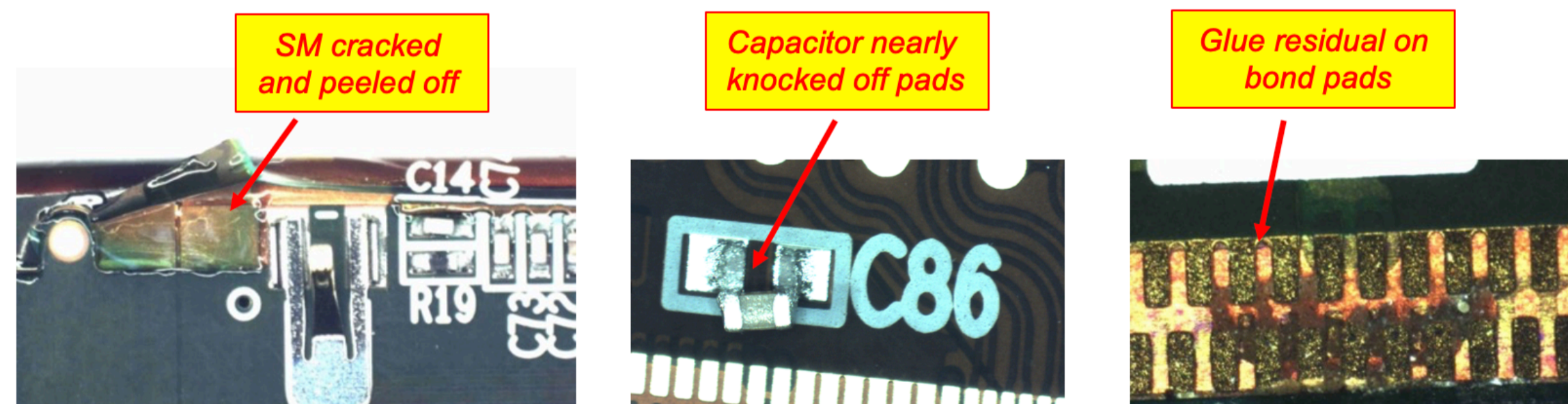
Common Front-End Hybrid technology

- HDI polyimide flex circuits
 - 42.5 μm tracks width and spacing
 - 25 μm laser copper filled micro-vias
 - down to 500 μm radius tight fold
- High speed differential pairs:
 - 90 Ω in 150 μm, 4 layers thin flex
- Carbon fibre stiffener:
 - high thermal conductivity laminates
- CTE compensators to eliminate bow
- Al-N spacers in the hybrid to allow for same bond height substrate surfaces between hybrid and sensor

Hybrid visual quality control, mechanical measurement and thermal cycling tests

The **visual inspection** takes place using stereo microscopes with coaxial, ring and external lighting and consists in inspecting and evaluating:

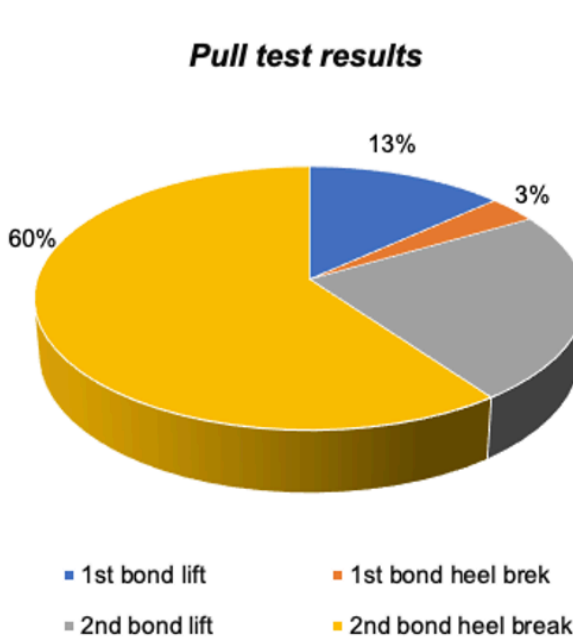
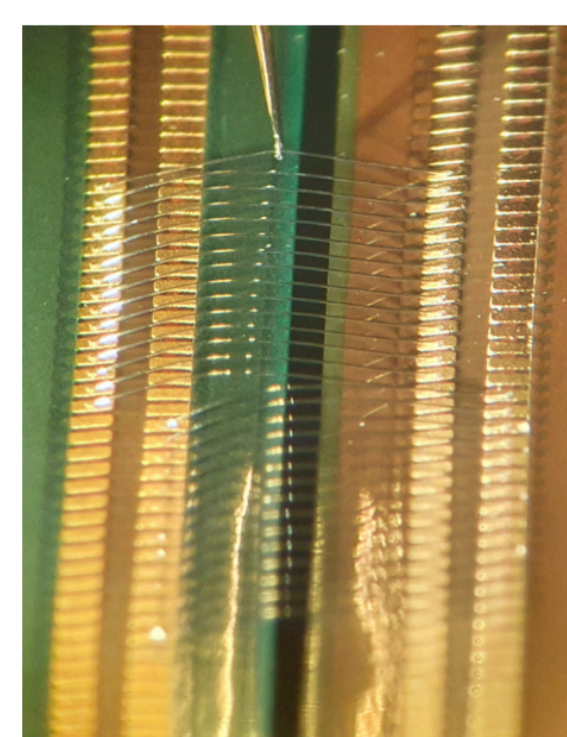
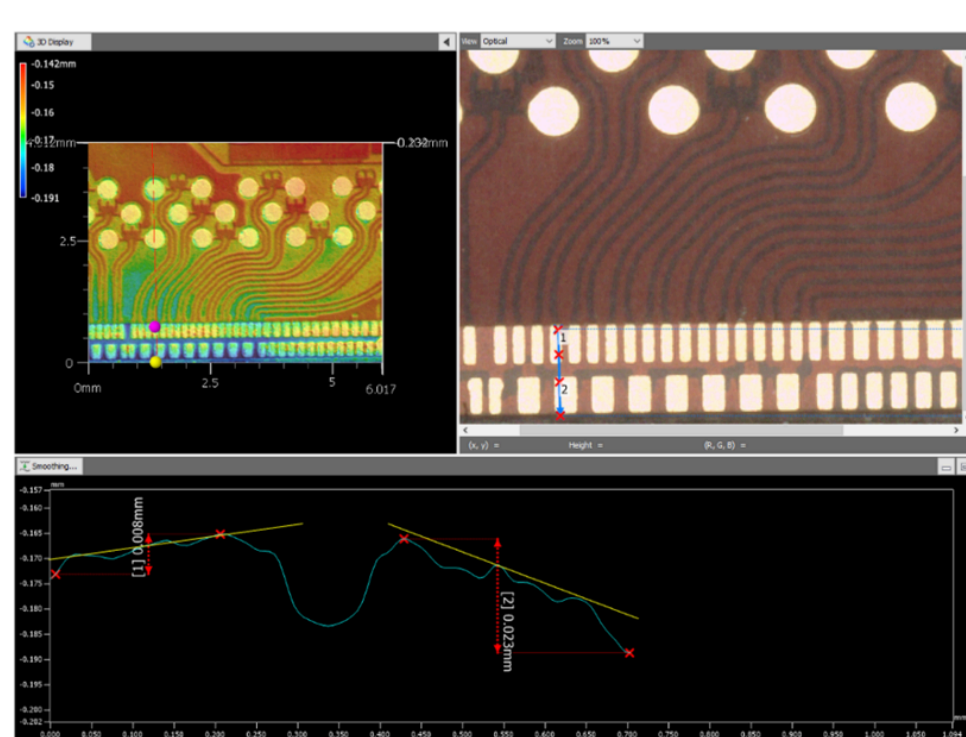
- **components soldering and placement quality**
- **alignment and adhesive quality of hybrids element** as flex, stiffener and compensators
- **evaluate cleanliness of circuit** (incl. interior of connectors)
- **bond pad quality** (where applicable)



Main reasons to include the visual inspection in the hybrid quality control plan:

- The wire bondability is critical and if it fails, the modules fail. The bondability depends on many, mostly mechanical and chemical issues, some of which can be detected visually and via measurement
- The precision of the mechanical properties of these hybrids for module assembly has a much higher standard than in the past detector
- The reliability (mechanical and electrical) is critical given the harsh environment and long lifetime required of these hybrids, thus electrical functionality is not sufficient

Bond pads evaluation

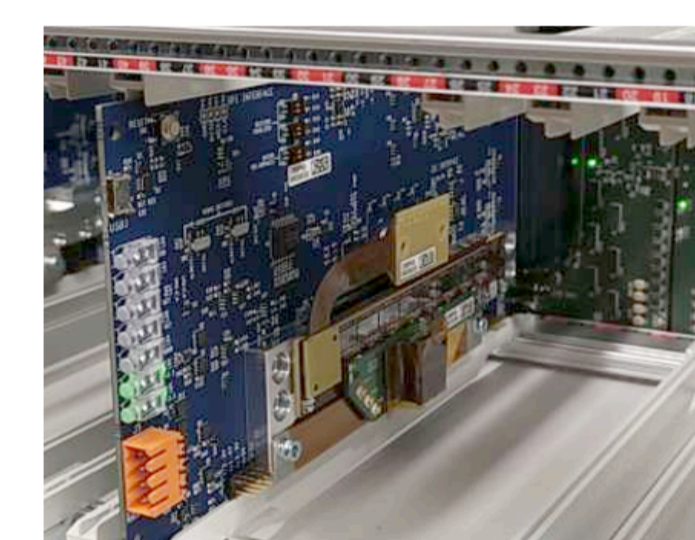


The acceptance of the hybrids requires to pass **electrical** and **functional tests** that are carried out with a crate based on a multiplexing platform.

[Ref.: M. Kovacs, et al., PoS TWEPP2019 (2020) 082]

In addition, **characterization** and **stress testing** of a sample of 2S-FEH prototypes are performed at nominal operating temperature of – 35°C

- Including thermal cycling between – 35°C and + 20°C
- Ensuring reliable performance at edge condition of what can be expected during the CMS Tracker operation/ lifetime
- Test cycle:
 - Look for short and open loops
 - Inject stubs using noise and check that the check that the correct stubs are measured by the CBCs (correlation plots)
 - Pipeline address test
 - Offset register test
 - Pipeline/Buffer RAM test
- Visual inspections performed before and after temperature cycling:
 - No indication of mechanical damage to flex hybrid from ~20 thermal cycles between 20°C and -35°C



- **Thanks to the visual inspection, electrical control and characterization made on the hybrid prototypes valuable inputs were provided to the contractors to finalize the design of the hybrids assessing aspects related to mechanical assembly and interconnection properties.**
- **The Hybrid project is overall on track and entering in the pre-production phase of the CMS Outer Tracker Upgrade project.**