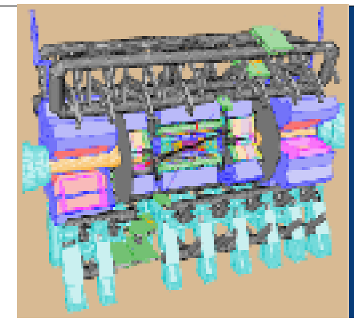

ATLAS Pixel Mechanics

Composite Materials, Ultra Stable Platforms, CAD Integration, Thermal Management, Multi-chip Module Assembly, Metrology

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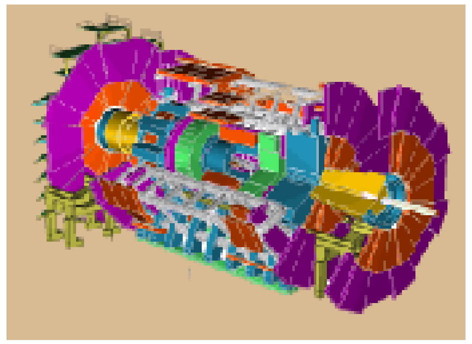
The ATLAS Detector (A Toroidal LHC ApparatuS)

The LHC (Large Hadron Collider) is under construction at CERN (European Organization for Nuclear Research, Geneva). The ATLAS detector, having an overall cylindrical shape with both length and diameter exceeding 20 meters, and a mass of 15,000 tons, will be located at Site 1, one of the six LHC interaction points. The particle beams go through the detector along its axis and collide at the center. ATLAS consists basically of three sub-systems nested inside each other like Russian dolls: an inner tracker at the center, the calorimeters, and —surrounding the others— the muon system. Commingled with these are superconducting magnets that set up solenoidal and toroidal fields deflecting particles to measure charge and momentum.

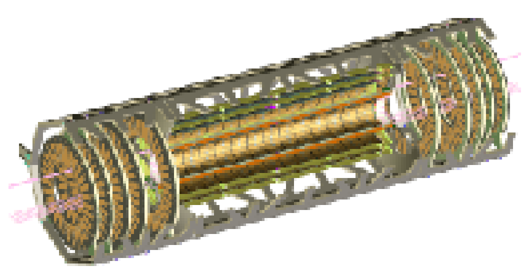


The Inner Detector

At the center of ATLAS is the Inner Detector, which has very stringent specifications: i.e., to track thousands of particles to a spatial resolution on the order of tens of microns inside a volume of 28 cubic meters. It sits in a cavity 2.3 m in diameter, 7 meters long, wrapped around the interaction point. The detecting elements (sensors) and their associated electronics have high intrinsic resolution, but the mass and stability of the mechanical structures can generate large tracking errors. The Inner Detector consists of three subdetectors of increasing resolution (TRT, SCT, and Pixels), each relying on different technology to resolve tracks. Mechanically, the Inner Detector consists of three assemblies: a barrel extending from +/-0.8m, and two forward trackers, extending from end of barrel to end of tracker, with a gap between the two for services. The Pixel Detector lies entirely within the Barrel Region.

Three different detector technologies are used. The Pixel Detector is designed to provide three very high granularity, high precision (>12 μm), sets of space points as close to the IP (interaction point) as possible. The SCT (Semi-Conductor Tracker) uses microstrip silicon technology, and provides four intermediate precision space points. The TRT (Transition Radiation Tracker) uses gas straws to give up to 30 space points per track, as well as being used to identify species of particles.

The Pixel Detector



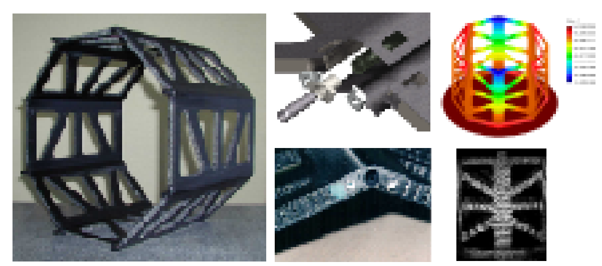
A pixel sensor is a 21 x 62 mm x 250 micron wafer of silicon with ~50,000 pixels, 50 x 400 microns each. There are over 2000 modules in the Pixel Detector, for 140 million channels in a cylinder 1.6m long and 0.5 m in diameter. The front-end chips are a major heat source (1.0 W/cm^2), dissipating more than 17 kW into the detector volume. This heat is taken out via integrated cooling channels in the detector local support elements. The aim of the support structures is to provide a stable base for all of the modules from which to measure. Because of the high intrinsic resolution (12 μm in r-φ), stability motion; on the order of 5 μm or more are intolerable. Build accuracy is much less stringent, however, at 50 μm global position of each module, it is still very challenging.

Module support elements in the barrel region are stave-like, and in the forward region there are sectors. Modules are fixed directly to the local supports via a semi-rigid, thermally conductive adhesive so that the structure will provide cooling to them while minimizing the bi-metallic effect. This breakdown of the substructure allows for easier assembly and maintenance, as well as modularity and testing. As each module can cost 5kchf ($3,000), it is important not to tie them all to one structure.

As the Pixel Detector is the innermost of all detectors within ATLAS, it sees the highest radiation dose [(10^{15}neutrons/cm^2 (hadronic) and ~1 MGy (ionizing)], which is nearly 100 times that encountered by a satellite. To increase the life of the silicon in the SCT and Pixel systems, they must be operated and kept at or below –7° C. Because of the stringent stability requirements and the harsh operating environment, all of the support structures for the Pixel Detector are made from composite materials for their high thermal and hygroscopic stability, and low mass (high transparency).

Global Support Frame

Berkeley Lab is responsible for providing the Global Support Frame, the primary integrating structure of the Pixel Detector. It must meet severe design requirements for stiffness, hygrothermal stability, and radiation hardness. In designing the support frame, we start with a careful description of the requirements, develop prototypes, test them, and then feed the test results back into the design. For the support frame, we investigated several composite materials: a carbon-fiber honeycomb, and vitreous carbon foam sandwich structures with UHM Graphite/Cyanate-Ester face sheets. These materials have excellent stiffness/weight ratio, very low CTE (coefficient of thermal expansion), and low CME (coefficient of moisture expansion) —a problem when the material dries out. They are also sufficiently radiation tolerant for our application.



Both single panels and bi-panel units were tested. Bi-panel units were tested to better understand joint compliance prior to final design of the full prototype frame. The main test method used for the panels was TV holography, which can show the small strains of the prototype frame under load. Test results showed reasonable agreement between FEA predictions and measurements.

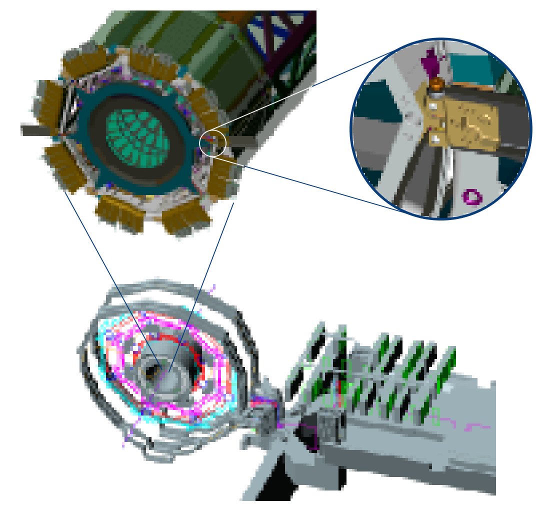
Module Mechanics

In addition to being a complex electrical entity, a module is also a mechanical assembly. Each module is composed of 16 front-end chips "bump-bonded" to the underside of a sensor wafer, on top of which is laminated the Cu-Kapton Flex Hybrid.

Berkeley Lab is developing an assembly and test facility for these and other multi-chip modules. Electrical interconnect is achieved via automated wire bonding of FE chips to the "Flex-Hybrid" high density interconnect. One important aspect of module assembly is the development of quality assurance measures for module production and detector assembly. Mechanical prototypes are used to quantify thermal performance and mechanical stability of modules.

Pixel Detector Integration

Berkeley Lab is the primary integration site for the ATLAS Pixel Detector. A major element of the integration effort is the interface of service runs to the Global Support Frame. Additionally, how these services are terminated to the local supports is of extreme importance, as this can affect overall stability. The service runs, starting in the detector volume, must be routed all the way from the Inner Tracking volume out through ATLAS, and into the Service Areas housing the Racks and Off-Detector Electronics and Readout. As the Pixel detector is the innermost of all detectors, this routing has interfaces with all other detectors and subsystems of ATLAS. LBNL has taken on this role to better control all aspects of our deliverables.

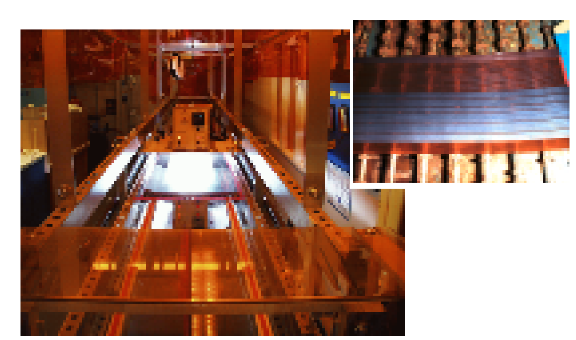


Low-Mass Cables

The Pixel Detector is buried in the tracking volume of every other detector of ATLAS. As such, everything about it must be optimized for mass. This is particularly true of the services, as they represent a fairly large cross-section of inactive material to all tracks traversing the volume.

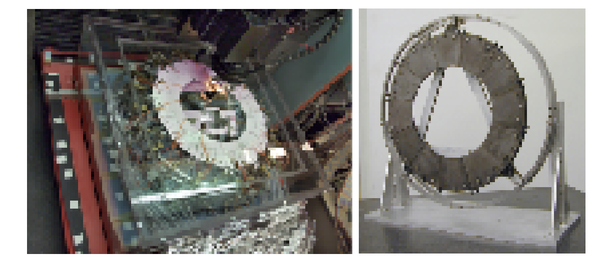
Berkeley Lab is uniquely qualified to produce cables for the ATLAS project. We have had excellent success fabricating prototype Copper-Kapton flex cables. We have succeeded in fabricating cables up to 14 meters long, using a process that is fairly quick and relatively inexpensive. So far, private industry has shown no interest in fabricating cables of this size.

The basic process uses roll lamination to apply a photo-resist and a photo-imageable coverlay. A UV exposure lamp on a trolley exposes the full length of the artwork, while the laminated Cu-Kapton is held between the art layers under vacuum. A continuous-feed etch process finishes the cable.

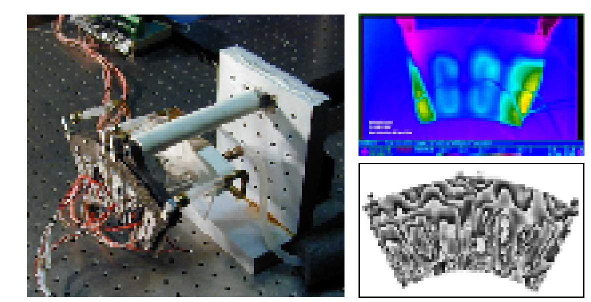


Local Support

Berkeley Lab is also responsible for the design of the local support system in the forward region. The finished modules are attached thermally and structurally to these elements (called sectors). Sectors provide both support and cooling functions for the electronics. Several sectors (11 or 9) are assembled to form a pixel disk. A prototype 12-sector ESLI disk is shown below.



The sectors must also meet stringent design requirements with respect to stability, thermal performance (at 20°C, the electronics will generate 1 W/cm^2, ~60 W/sector), and radiation hardness (elements must be radiation hard to 300 kGy). In designing the sectors, we used the same methodology used to design the frame: start with a careful description of the requirements, work out prototypes, test, and feed the results back into the prototype design. TV holography and infrared (IR) imaging are used extensively to qualify sector designs. Shown below is a thermograph of an LBNL aluminum tube sector, along with a bi-sector TV holography setup and phase plot taken at HYTEC Inc.



We are investigating three tube technologies for the disk sector options: flocked glassy carbon, sealed Carbon-Carbon, and aluminum, in order of mass. The first two options involve SBIRs (ESLI for the glassy carbon, HYTEC for the Carbon-Carbon tubes); the third option (aluminum sector tubes) is produced at Berkeley Lab. All sectors use Carbon-Carbon face sheets for its superior through the thickness thermal conductivity, and low CTE/CME.

All sectors have equivalant interfaces to the support and modules.