PROCEEDINGS OF SCIENCE

New Technologies in Mechanics for Tracking Detectors

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The talk is first based on a feedback of the technology used in the current Barrel SCT (ATLAS experiment), and the recent AMS02 Tracker detector (Space experiment on ISS). The challenge for the Barrel SCT was to build a detector with a highly accurate positioning and a very stable behaviour (within 10 microns) and keeping the material budget as low as possible. In AMS-02 the environment was non common, both in term of mechanical load (up to 6g) and temperature changes over every orbit. The simulations and testing, pushed to the limits, led the designers to come up with an optimized detector.

It gives, in the second part, an outlook towards the new R&D for the next Tracker generation (among Insertable B-Layer, and ATLAS Upgrade Phase II). It was mainly focused on mechanical architecture and a state of the art of the materials.

The aim is also to identify some common developments among future projects so that a global effort could be done to further optimize the "system" as a whole… not only from mechanics side, but also including the "electronics" parts. In a kind of "all integrated" approach! Some tools already exist which only need to be better used (CAD, FEA, …).

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[1] Speaker

1.Introduction

The « Departement de Physiques Nucleaire et Corpusculaire » (DPNC) has been involved, over the past twelve years, in two major projects related to tracking detectors: AMS02 Tracker and ATLAS SemiConductor tracker (SCT). On these two projects, the material budget was very stringent, and the weight optimization along with material and design shape has been pushed close to the limits. Each project has its own characteristics and the way to optimize the mechanical structures is quite dependant on the environmental conditions, whether it is part of the underground Atlas experiment at CERN or it is installed on the International Space Station (ISS).

The ATLAS collaboration is now looking towards the new generation of tracker experiment as part of the ATLAS upgrade development. The upgrade scenario is defined according to the following scheme: a first step will be to insert a new “B Layer” as part of the current Pixel detector, called IBL standing for Insertable B-Layer, then a new complete Pixel system will replace the existing one (in the timescale of 2017-2018), and last a full inner tracker will be built (beyond 2020).

The upgrade will investigate new techniques and materials in order to cope with the challenging reduction of radiation length. Its R&D work has led so far to the use of the most advanced carbon fiber material in mechanics, carbon foam for thermal management, and on mechanical design where electronics and thermal compounds are merged into one unique system. The simulations with finite element analyses (FEA) is vital to save material while keeping the stability of the system, an increasing number of institutes are stressing the importance of such studies for both mechanical and thermal aspects to be coupled with tests.

2. Past Experiments: ATLAS SCT & AMS-02

2.1 The ATLAS Barrel SCT project

The ATLAS Barrel SCT, shown in figure 1, was installed into the ATLAS Inner Detector in September 2006. It consists of 2112 hermetically tiled modules, arranged on four different cylinders [1].

The module is made of silicon micro-strips sensors, hybrids, flex circuits, connectors (Figure 2) and is fixed to the honeycomb cylinder structure by means of two inserts in peek material. A third fixation point is given by the module that is mounted nearby on the next row. The module entity is then held in position by one thin individual bracket in carbon fiber reinforced plastic (also known as CFRP) which provides the precision and stability between modules.

Services and cooling system is supported by the carbon fiber structure.

Figure 1: Barrel SCT during Insertion thru TRT

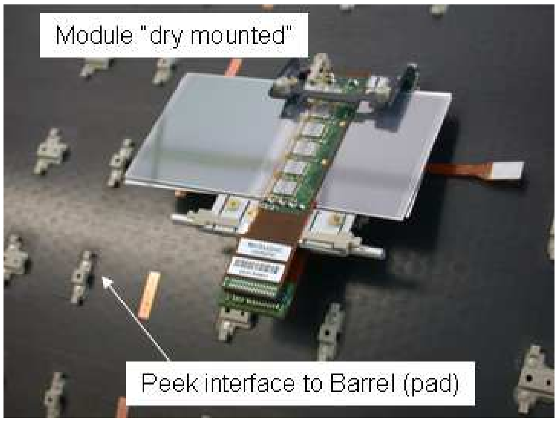

Figure 2: Module SCT (w/o services)

Main features:

The use of honeycomb structures in carbon fibers (XN50/RS3 facing) led to a very stable structure in terms of thermal expansion, stiffness and moisture absorption. The stiffness also helped in doing the re-machining for each insert in peek in order to get the final precision (within 50 microns). However, a few inserts have been slightly de-bonded after machining which obliged to some late modifications in order to secure all the inserts before module assembly (bolting).

The resulting precision at “module-to-module” level was very good (50 microns), while the intrinsic precision at module itself (double sided) was of the order of a few microns.

Module assembly:

The conceptual approach led the designers to mount the modules one by one, with a very small clearance to all the services on the structures, which was not trivial due to the large amount of modules to be assembled onto the cylinders (2112). A robot system was developed jointly by KEK and UK to cope with the tricky kinematic and the repeatability issues. Also, to populate the cylinders with the modules in this way forced the whole barrel assembly to be done after the modules have been loaded to the structures. This remains a very delicate operation with sensitive parts on big structures to be moved by means of “cradles”.

The next tracker generation will take some of the above complications into account in order to provide an easier way to assemble things and to guarantee better modularity.

2.2 The AMS-02 Space experiment

Figure 3: AMS-02 as installed in May 2011 on the ISS.

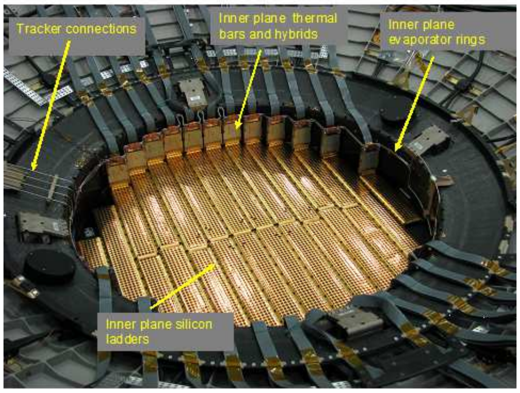

Figure 4: Silicon ladders of the Tracker (One inner plane seen from the top)

The AMS-02 experiment is a spectrometer that was installed on the International Space Station (figure 3) back in May 2011. It followed the first flight of AMS-01 with the Space shuttle for nine days in 1998. The mission with AMS-02 is now foreseen to last more than fifteen years in space.

The core of the experiment is made of a permanent magnet and a silicon tracker inherited from the AMS-01 version. The Tracker is made of “silicon ladders” (figure 4) sitting onto honeycomb panels, 4 detection planes in the “core” and 2 others outside the inner volume (in the latest modified version).

The particularity of such project lies in the environmental conditions: the “logistics” (space shuttle) which drives the design to withstand both vibration and quasi static loads (for instance, acceleration up to 6g including a margin of safety, first Eigen value above 50 hertz as a general rule), and the thermal environment which creates a cycling every 90 minutes (period of the orbit around the earth).

Even if the different environmental conditions are quite decoupled in the sense that thermal loads start after reaching weightlessness, they are anyway really stringent in the case of a Tracker detector which requires being light and stable in the same time to meet the requirement of the launch. The “equation” is tricky and led the designers to go for a structure all in carbon fibers for the outer box, and the detection planes made of honeycomb panels (best ratio between weight and stiffness).

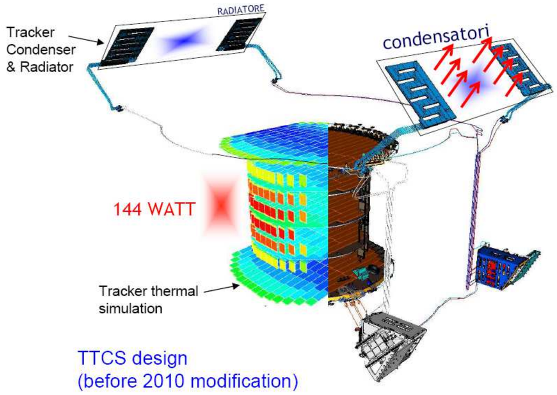

Figure 5: Tracker cooling system in CO2.

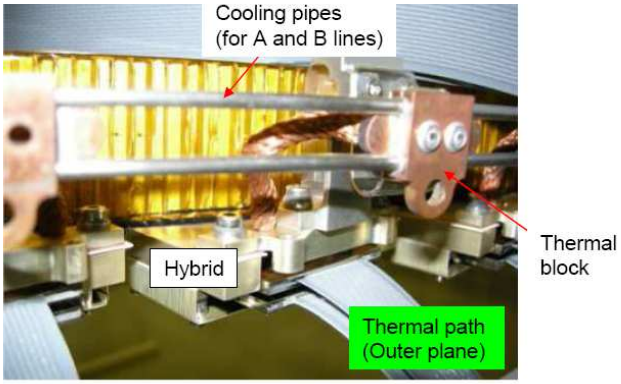

Figure 6: cooling connection to hybrid

Another issue was to guarantee a thermal stability at the order of 3°C over each orbit which led to go for an active cooling in a two phase system in CO2 [2] (figures 5 & 6). The system has been fully tested and validated before launch, at ESTEC (Holland), in 2010 (thermo vacuum chamber).

Main features:

Unlike most of the “on ground” experiment, a space experiment has to undergo a series of stringent tests in order to be validated. As an example, it has to experience vibration tests on a shaker (full system, or a sub part), thermo vacuum tests that recreates the space environment as close as possible.

The choice of material is driven by both physics and the rule in space where no out gassing material is allowed, and only “well known” material are permitted which restrict the choice of material to be used (exotic or new materials are suspicious by definition!).

Simulation by finite element analysis in space experiment is mandatory to validate things at different steps: from the preliminary design review thru the final critical design review. Also, the testing activities are a basis to correlate with analyses which permits a fine tuning of the thermo mechanical behavior.

3. Outlook towards ATLAS upgrades: IBL, Pixels, and Strips detectors

The present document describes the ongoing developments on each of the future ATLAS Upgrade phases of the Inner Tracker: the IBL project as an intermediate step in 2013, the new Pixel to be installed in 2017 to replace the current Pixel, and last phase is the complete replacement of the Strip detector (both Barrels and End caps).

3.1 IBL project

The IBL is to be installed in 2013 at CERN together with replacing the existing beam pipe. The IBL will be "attached" to the new beam pipe (47 mm ID), and inserted thru the current Pixel by pre inserting an IBL Support Tube (called IST). The full package (IBL, Beam pipe, IST shown in figure 8) will be then adjusted in position by acting on the current suspension mechanism.
The major development is focused on both the IST optimization, and the IBL Stave design.

IST design:

The radiation length is so stringent that the IST shouldn't exceed 0,5 mm thick carbon fiber (85 mm ID, over 6600 mm long). In order to keep it stiff enough, the choice of using very high modulus fibers (VHM, prepreg type: K13C/RS3) has been made and another constraint was given by the maximum length to build the part: to get the mandrel easy to do, to be put into an autoclave. This led the designers to deal with 3 to 5 elements to build the full object (6600 mm long). Then the challenge was to validate the joint fixation by gluing (load test). This is now under prototyping at Seattle (USA).

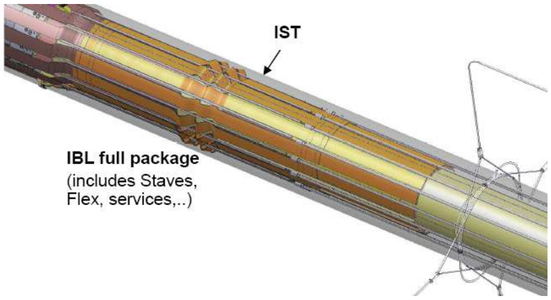

Figure 8: the full IBL assembly

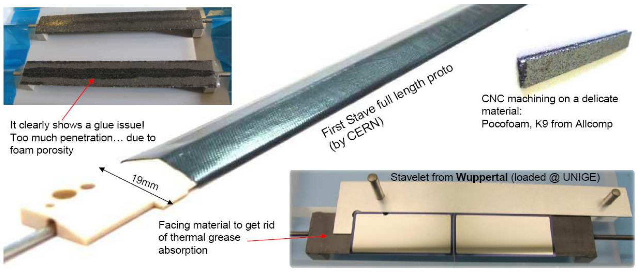

Figure 9: the IBL stave development

IBL Stave:

The IBL Stave is a mix of several high tech techniques and materials (see figure 9). On IBL, 14 staves will be arranged around the beam pipe. The Stave is the part which holds the modules together with the cable bus.
It has to be light, stable and has to transmit the cooling from the pipe to the modules. To do so, a long development has been carried out to define the proper carbon foam and glue which embeds the cooling pipe (K9 foam). The foam is then "closed" by a V shape carbon fiber plate and a facing plate of the same material (K13C/RS3, 0.19 mm thick).
The IBL Stave fabrication is now under way in Wuppertal, the first Stave prototypes have been received in DPNC for module loading phase. Some thermo mechanical tests have been initiated in order to fully understand the whole behavior of a Stave and correlate them with simulations.

3.2 Pixels

The group in Berkeley (LBNL) is developing a new approach for the 2017 Pixel replacement: instead of having independent staves fixed to a global frame, the idea is to build a kind of double stave structure (called I-Beam, see figure 10) in order to rely on its own stiffness.
This provides a self supporting structure so that the whole system can be further reduced in term of weight and material.

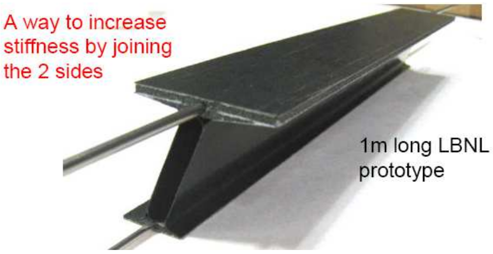

Figure 10: the I-beam conceptual approach

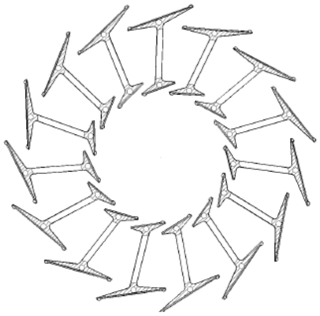

Figure 11: the I-beam assembly

The design of such "Stave" shows some common development (usage of carbon foam, K9, and prepreg material, K13C) with the IBL Stave. Some prototypes have been built to test the stiffness of such an approach along with a fine tuning of the whole processing (mold, counter mold, amount of glue …).
The next step is to provide a complete assembly model (figure 11) with details on the way to fix the I Beam staves respect to each others (including services).

3.3 Strips

The current Barrel SCT, as shown in paragraph 2.1, is based on individual modules to be populated onto 4 barrels. This is a quite modular approach except for the cooling lines which are preassembled prior the module installation (4 module rows per 1 cooling line). When everything is assembled (4 barrels), any rework on modules belonging to the inner barrels will bring to a complete dismounting of barrels to get access. Same issue on cooling lines, if something fails a lot of modules need to be removed.
That's why for the next generation of Strip detectors, it has been put as a first level of constraint what is called the "End Insertion" (applied to the "Local Support"): when everything is assembled, any module (and Local support) is then accessible from each Barrel end and can be removed in a relatively short time. This is the key feature for the next strip detector. 12 Modules are positioned and fixed onto a Local Support (Stave / Super Module / Petal for End cap) which also hold each cooling line (1 line per 12 modules).
On Barrel Strip, several competing approaches are studied to provide a Local Support: Stave and Super Module (see next figures 12 and 13).

Figure 12: Stave development at RAL (UK)

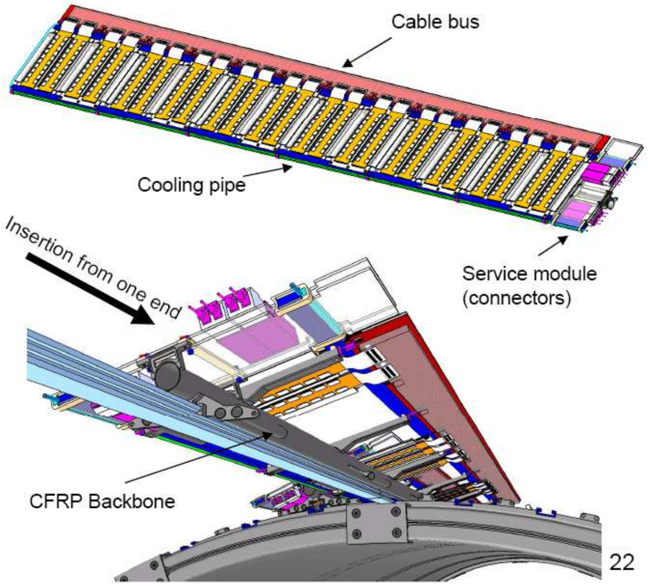

Figure 13: Super Module with its End Insertion

In the development of the Stave, which is a common project between LBNL, BNL, and UK groups, the cooling line is embedded into the core of the sandwich panel (carbon foam, 2 facing prepreg), the modules with hybrids are directly glued on both sides of the sandwich. The number of fixation points on the structures depends on the stiffness that is required (about 6 points so far). By its own, a Stave is considered as a non rigid object which needs a multi point constraint on a stiff structure (the barrel) to be made stable. Several systems to hold the Stave on the Barrels are under development at RAL, BNL, or even at DPNC. Many investigations are underway to estimate the behavior of the Stave, where in particular its stability to temperature and the quality of the cable bus bonding to the Stave facing prepreg is a concern.

In the Super Module approach developed by DPNC and KEK, modularity is kept all the way long its assembly process. This means that a “Module” entity can be taken out of the Super Module without scarifying any sub part, by unscrewing the “module” from a support structure (cooling plates). It can be easily replaced by a spare module in a reasonably pretty fast process (no wire bonding to the cable bus, only connectors).

There is a kind of “backbone” made of Carbon fiber material which is the main support structure of the Super Module and can be assembled separately from the Module sub assembly (12 modules, 2 cooling plates, cooling pipe). Investigations are underway with prototypes to understand the mechanical stability of such approach.

The End Insertion has been fully validated in 2011 with prototypes, and exhibits a very good reliability in term of positioning.

4. Conclusions

The aim of the talk was to identify some common developments among the future tracker projects so that a global effort could be done to further optimize the “system” as a whole… not only from a mechanical point of view, but also by including the electronics parts (Front End boards, flex circuits,…) in a kind of “all integrated” approach!

It was shown a few examples on tracker experiments (past and future projects), which emphasize the key role that is played by the carbon fibre material (facing, foam) in terms of mechanical and thermal behaviour. This is now mandatory to correlate the simulation works with testing on prototypes, since the tendency is to get lighter and lighter structures while keeping the same requirements in term of mechanical stability.

References

[1] R.B. Nickerson et al. / *Nuclear Instrument and Methods in Physics Research A568(2006) 686-691*

[2] Bart Verlaat et Al, / meeting at CERN , *CO2 CernSeminar9April11.ppt*