Snowmass Letter of Intent:
Light-weight and highly thermally conductive support structures for future tracking detectors

Authors: A. Jung, B. Denos, S. Karmarkar, A. Koshy
Contact via: anjung@purdue.edu

Abstract

Detector mechanics can play a significant role in a detector's performance, improvements typically require in-depth study of total mass, novel ways to reduce the total mass, as well as more integrated design concepts to save on material budgets and optimize performance. The work proposed here benefits from ongoing efforts at Purdue University related to the HL-LHC upgrade of the CMS tracking detector. In particular, to design and manufacture large and small carbon-fiber-based mechanical structures able to support the CMS inner and outer silicon tracking devices. Progress made in regard to the HL-LHC detectors benefit also other future colliders such as a potential Future Circular Collider or a Muon Collider. Detectors at electron-positron machines have significantly smaller material budgets and require targeted concepts.

Introduction

Future colliders, such as the high luminosity LHC (HL-LHC), the Future Circular Collider (FCC-hh) and the muon collider (MC) will collide particles at unprecedented rates to search for new physics and make high precision measurements to challenge the standard model. The increase in granularity of the detectors and the background rates pose high demands for the materials of tracking support structures. Heat generated in silicon sensors has to be efficiently removed through the support structure to keep the sensors at the optimum temperature. In this environment typically carbon fiber composites are employed to build the mechanical support structures of silicon devices because of their high thermal conductivity, strength to mass ratio and radiation tolerance. These silicon devices facilitate precision position measurements and hence, require mechanical structures to be accurately assembled and precisely manufactured. The entire manufacturing process needs to be adjusted so that deviations/deflections can be predicted by finite element analysis (FEA), compensated and ultimately mitigated in the manufacturing of a final mechanical support structure.

Light-weight and highly thermally-conductive support structures

We propose to study light-weight and highly thermally-conductive materials that address a variety of urgent needs of future particle physics detectors, all aimed at the **Instrumentation Frontier (Precision support structures and cooling)**. By exploiting the experience gained from major responsibilities related to the HL-LHC upgrade of the CMS detector [1], namely design and manufacturing of multiple large mechanical support structure for the Inner and Outer Tracker of CMS including structures to mount the silicon devices. Figure 1 shows a few examples of ongoing activities at Purdue University that span low-CTE manufacturing and high-pressure curing to increase thermal conductivity [2]. Both of these are critical ingredient in the effort to reduce a detector's material budget yet provide a more precise and predictable support structure.

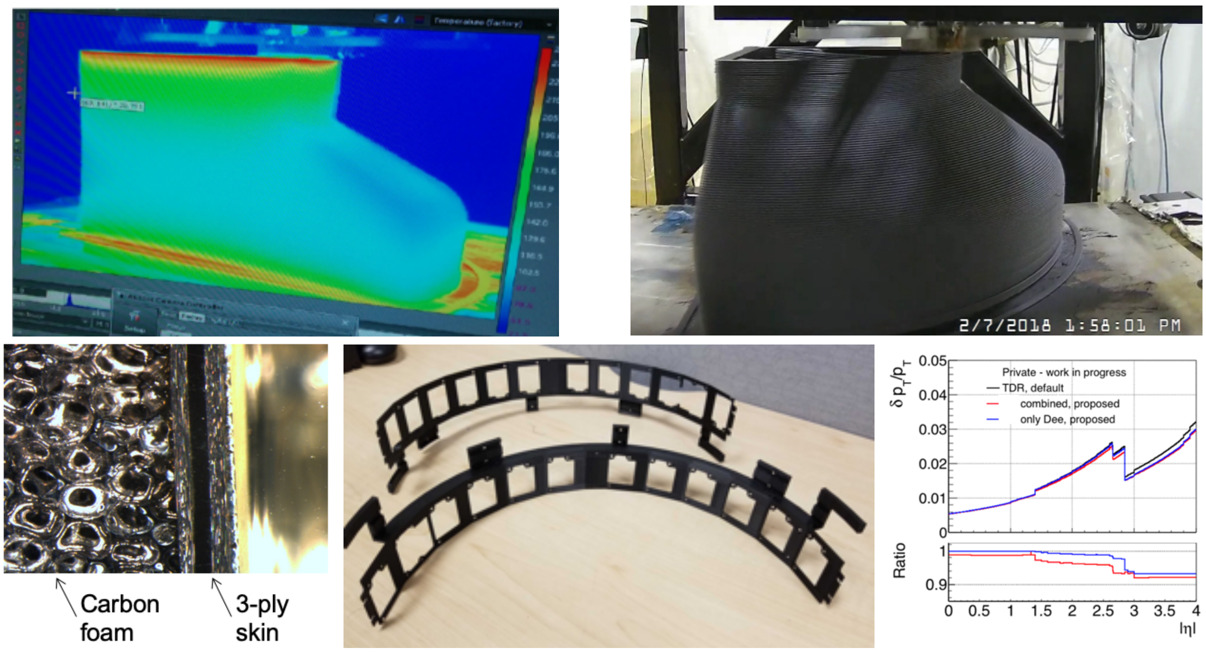

Figure 1: Overview of acitvities at Purdue University related to the HL-LHC upgrade of the CMS detector. Starting top left and clock-wise: thermograph of 3D printed mold; the 3D printed mold designed for minimal CTE mismatch; co-cured low mass support structure, 3D-printed prototype for a highly thermally conductive compression molded support structure; example of potential improvements for the CMS detector.

In particular, we hope to employ parametrized simulation and first-principle estimates to study the potential performance and bottlenecks of tracking detectors at future colliders. Our work aims to study solutions targeted towards more integrated cooling and mechanical support structures, which ultimately could be manufactured in a bottom-to-top approach using latest techniques such as 3D printing. We propose to study these novel techniques, materials and other design and manufacturing solutions in order to solve issues related to increasingly more complex tracking detectors.

References

1. CMS Collaboration, The Phase-2 Upgrade of the CMS Tracker, CERN-LHCC-2017-009, CMS-TDR-17-001 (2017).
2. R. Baker et al. "Full thermal characterization of anisotropic carbon fiber laminates", to be submitted to JINST – in internal review, 2020.