66: A study of simulation tools and manufacturing methods for multi-functional carbon composite particle detector mechanics and support structures

Sushrut Karmarkar [1,2,*]

Eduardo Barocio [1]

Benjamin Denos [1]

Justin Hicks [1]

Andreas Jung [1]

[1] Composites Manufacturing and Simulation Center, Purdue University

[2] Graduate Student, School of Aeronautics and Astronautics, Purdue University

* Sushrut.Rajendra.Karmarkar@cern.ch

Slack - @Sushrut Karmarkar

Improvements in Detector mechanics need in-depth study of thermal and mechanical loading conditions to have more integrated design concepts that save on material budgets and optimize performance. Particle detectors at future colliders rely on ever more lightweight and radiation-hard charged particle tracking devices, which are supported by structures manufactured from composite materials. This poster lays out engineering techniques able to solve challenges related to the design and manufacturing of future support structures. Novel manufacturing methods like Extrusion Deposition Additive Manufacturing (EDAM) along with associated simulation tools like Additive3D for prediction of part production and performance are highlighted with case studies from the High-Luminosity Phase Upgrade project for the CMS detector. Methodology for manufacturing of integrated support structures using simulation tools like COMPRO from Convergent Manufacturing Technologies is showcased for lightweight and highly thermally conductive support structures for future tracking detectors. Examples of current efforts at Purdue University related to the high-luminosity upgrade of the CMS detector are provided to demonstrate the prospects of suggested approaches for detectors at new colliders: a future circular collider or a muon collider. Specific geometric and design considerations for the proposed CMS Inner Tracker Rails are discussed to illustrate advantages and constraints for additively manufactured structures. The applicability, benefits, and uses of this technique to replace conventional tooling methodologies for composite layup part manufacturing are also highlighted.

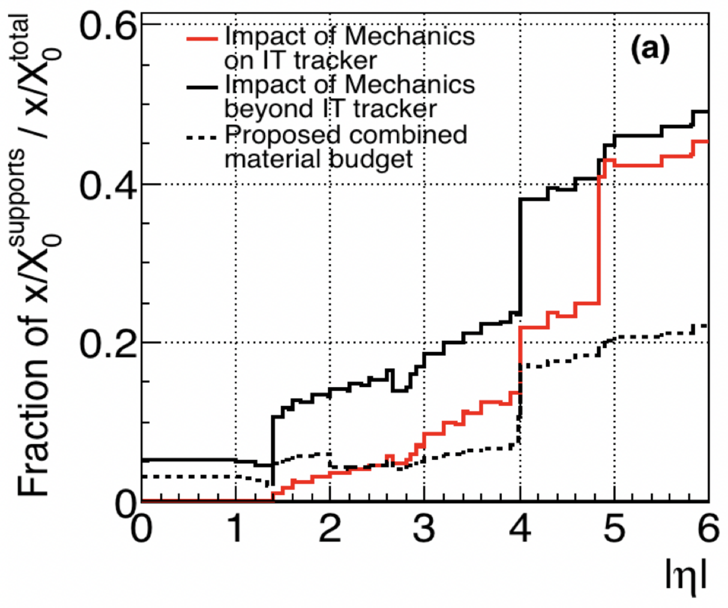


Figure 1: Preliminary result on fractional contribution of mechanics structures at FCC like detectors. The study follows a basic tracker design based on HL-LHC but extended in coverage.

Need –

1. Future high energy physics accelerators pose extreme requirements on the detectors surrounding the interaction points
2. Detector mechanics contribute to detector's performance, thus warrant an in-depth study of total mass, and the corresponding search for novel ways to reduce the total mass.

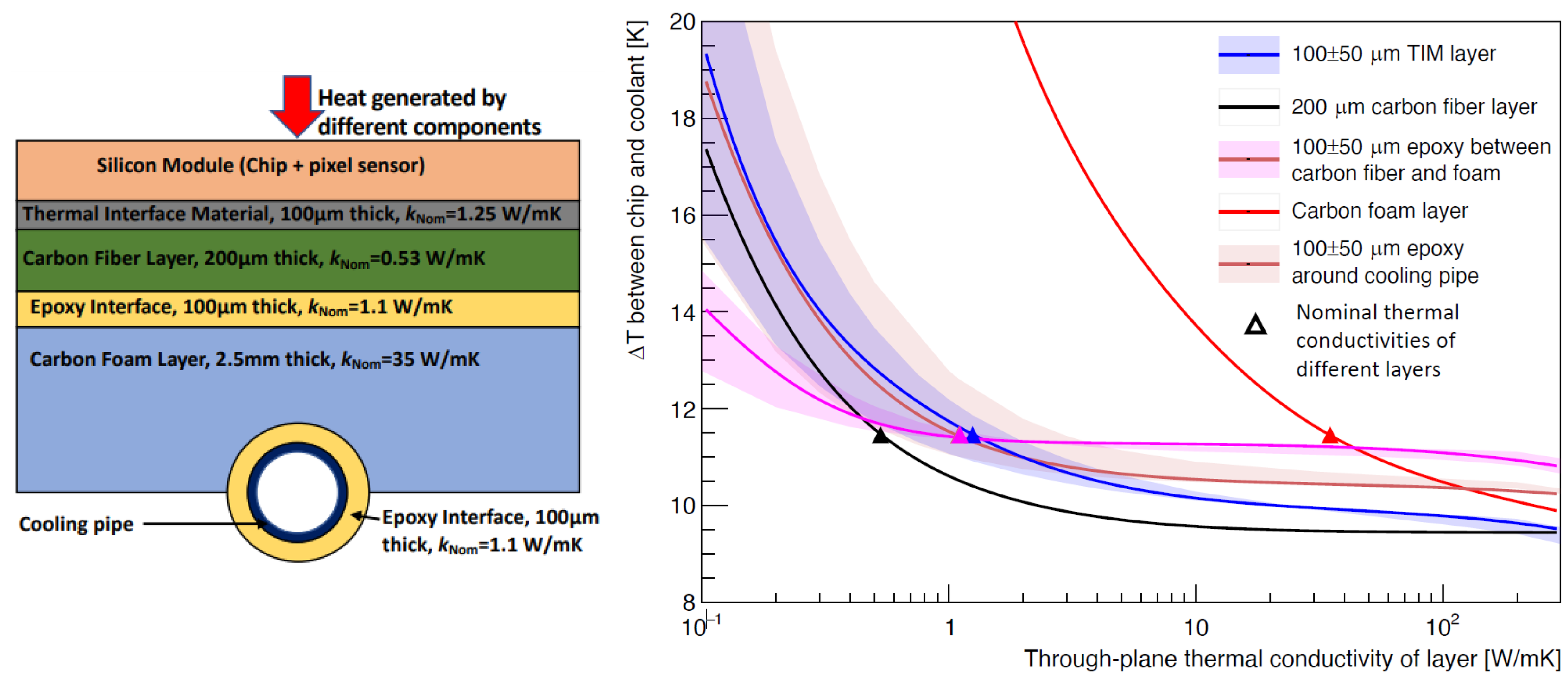


Figure 2: The temperature difference between the hottest point on the chip and the coolant as a function of the thermal conductivities of different layers of the hypothetical support structure used in current CMS detector. FEA simulation results are used to determine the functional form of the temperature dependence of the various materials. The shaded bands represent the impact of a ±50μm thickness variation for the various epoxy interfaces. Integrated and novel thermal management solutions will be needed for the higher energy levels in future detectors.

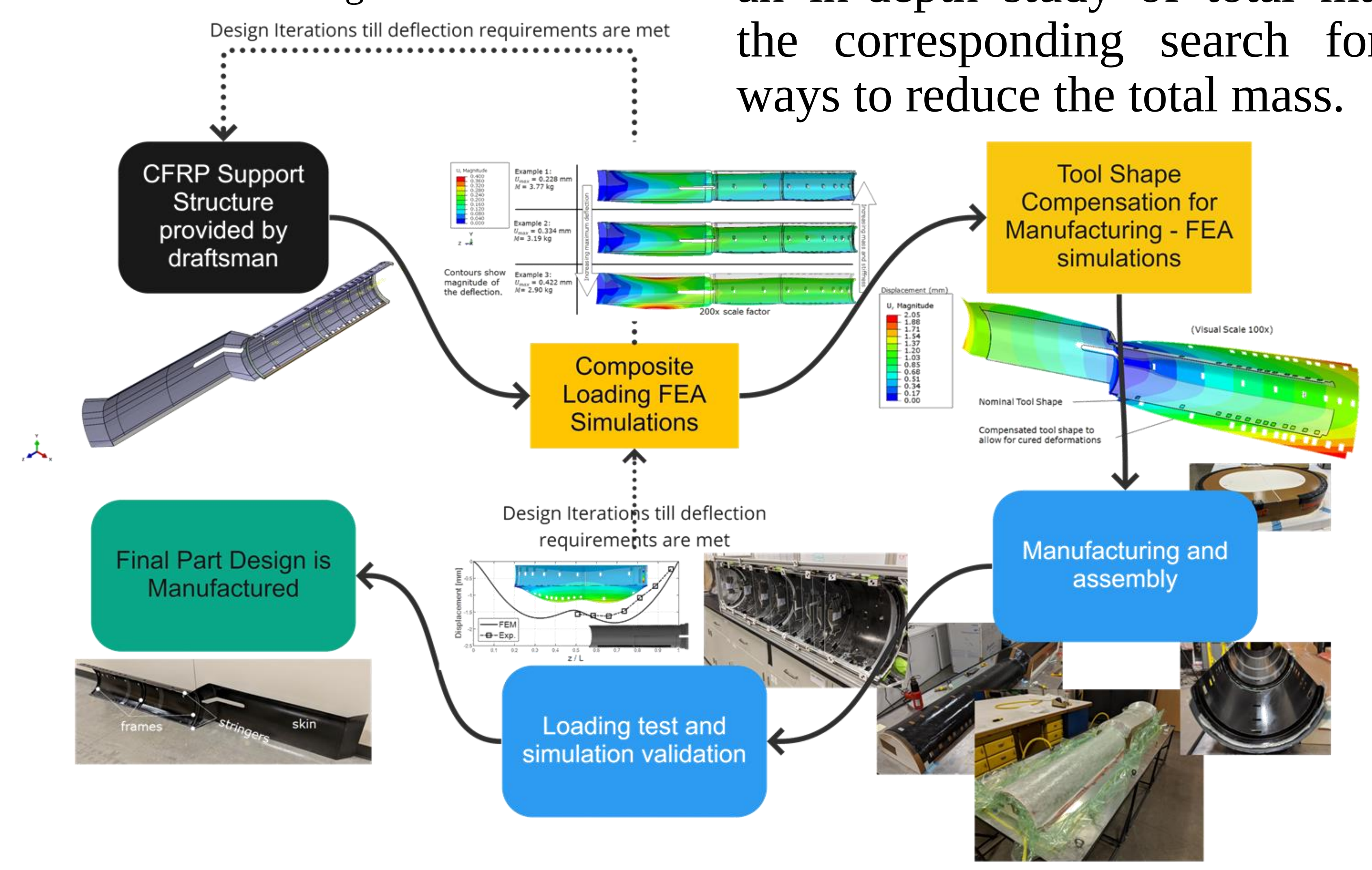


Figure 3: State of the art composite design methodology followed in the context of the CMS detector upgrades allows for manufacturing complex parts to the strict tolerances enforced by the physics requirements from support structures. This allows for prediction of the composite shape under various thermal, radiation and mechanical loading conditions.

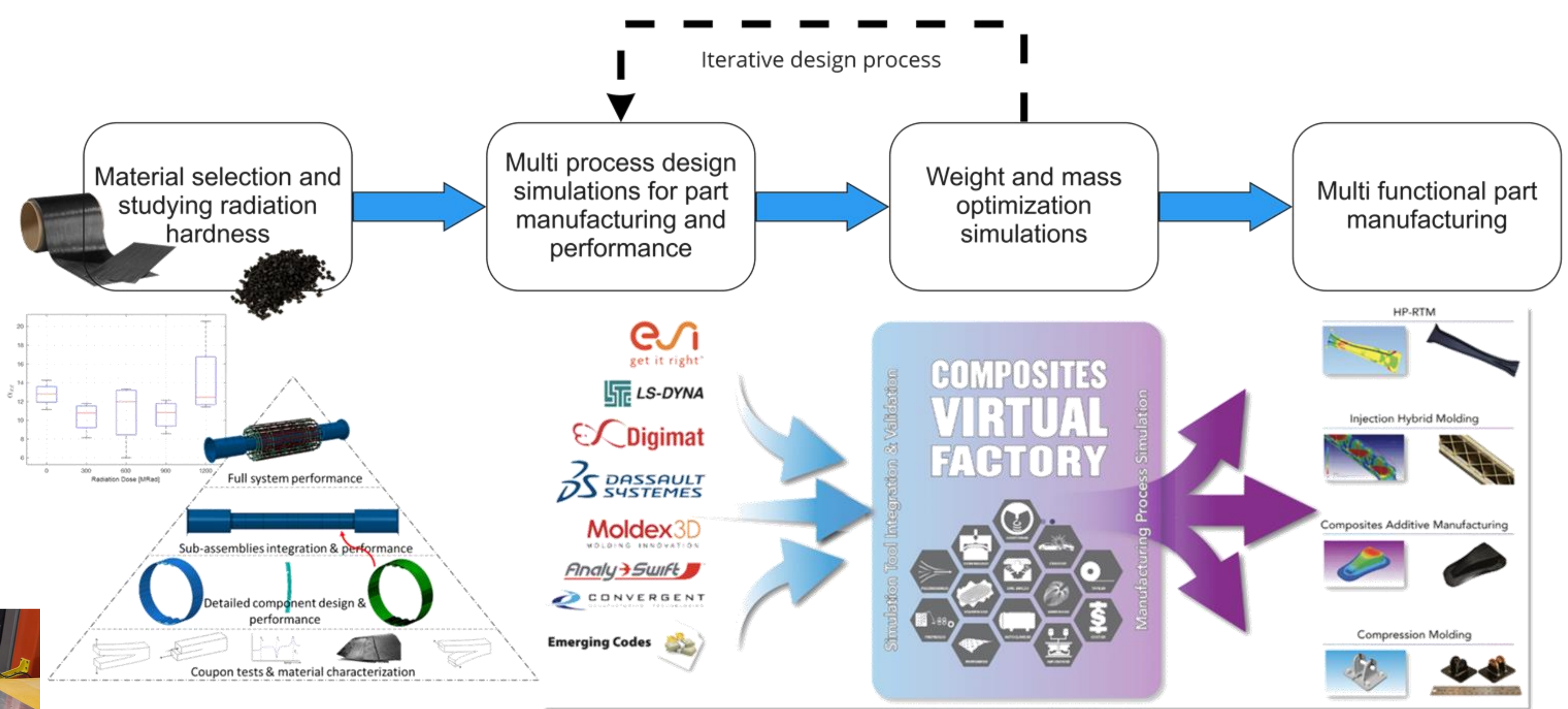


Figure 4: Multi-functional multi-process end to end analysis flow chart for process and performance metrics is presented for future detector mechanics.

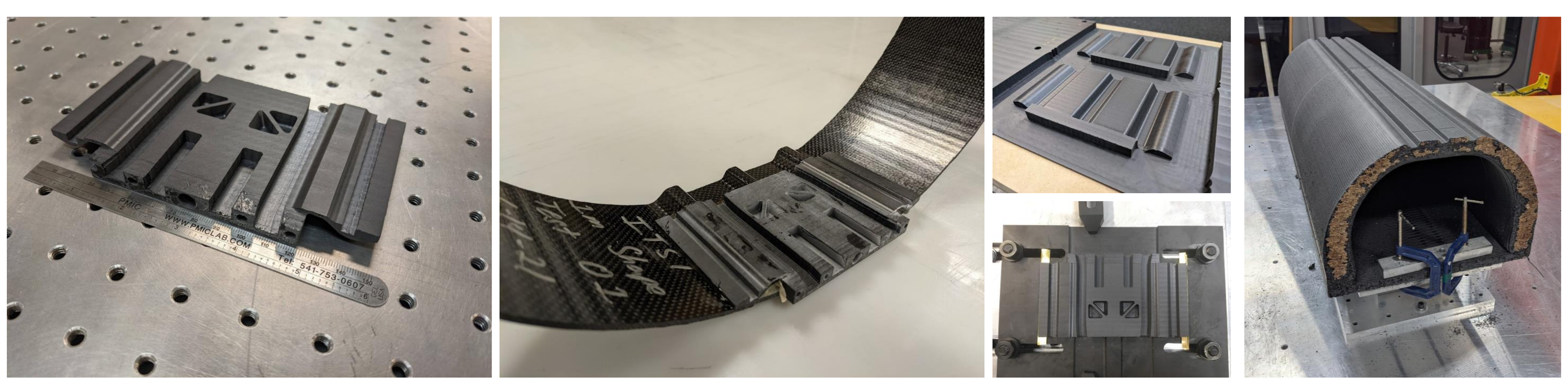
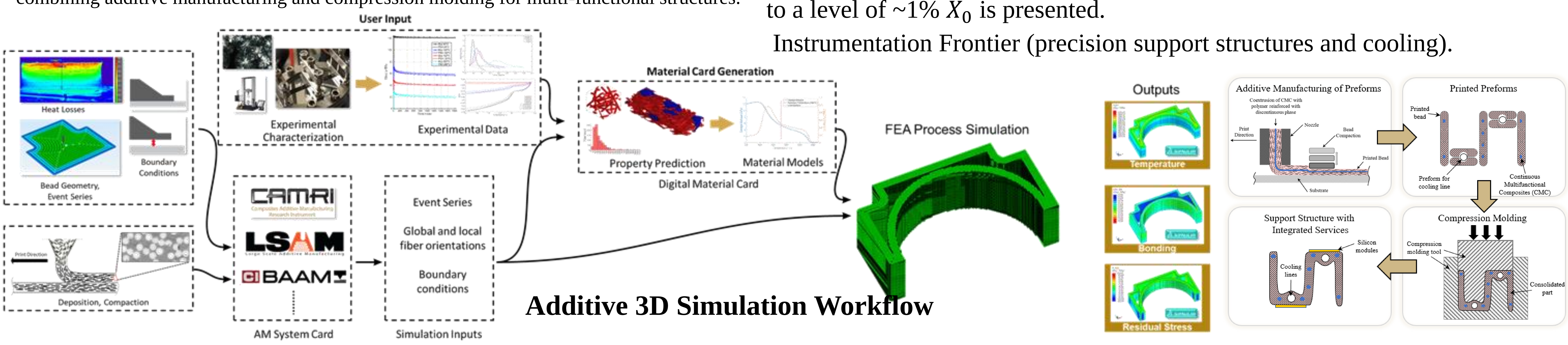


Figure 5: EDAM used for CMS high-luminosity phase upgrade structures and Additive 3D simulation workflow for composite part and performance analysis. Hybrid process combining additive manufacturing and compression molding for multi-functional structures.

Conclusion – Development of structural, lightweight, and highly thermally conductive composite tracking detector support structures and simulation capabilities for part and performance metrices; to reduce the radiation length per layer of a silicon detector at future experiments from the current ~2% X_0 to a level of ~1% X_0 is presented.

Instrumentation Frontier (precision support structures and cooling).



Additive 3D Simulation Workflow