The ATLAS experiment at the LHC

Haichen Wang

haichenwang@berkeley.edu

423 *** Hall

Physics 251

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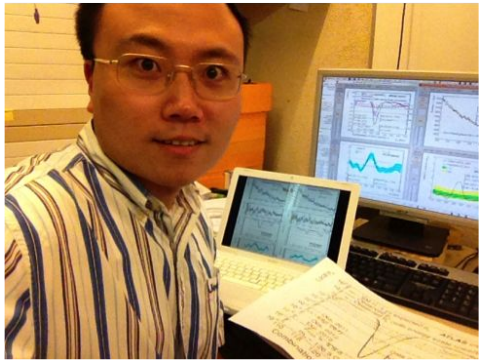
ATLAS EXPERIMENT

Berkeley UNIVERSITY OF CALIFORNIA

BERKELEY LAB
Lawrence Berkeley National Laboratory

Who am I?



2003 - 2007 Peking University BS in Physics

2007 - 2013 University of Wisconsin-Madison, PhD

4 yrs at CERN. thesis project: discovery of the Higgs boson

2013 - 2018 Postdoctoral fellow at LBNL

2019 - now Assistant Professor in the Physics department also a faculty scientist at LBNL

General comments

- The physics program at the Large Hadron Collider is the richest among all the particle physics experiments

- Collider experiments, unlike many other experiments, can see significant performance improvement over its lifetime
  - *new physics opportunities may emerge over the lifetime of the experiment, thanks to detector upgrade, ingenuity in data processing and analysis, and theoretical development*
  - *it takes ingenuity and hard-work of physicists to realize the new capabilities*

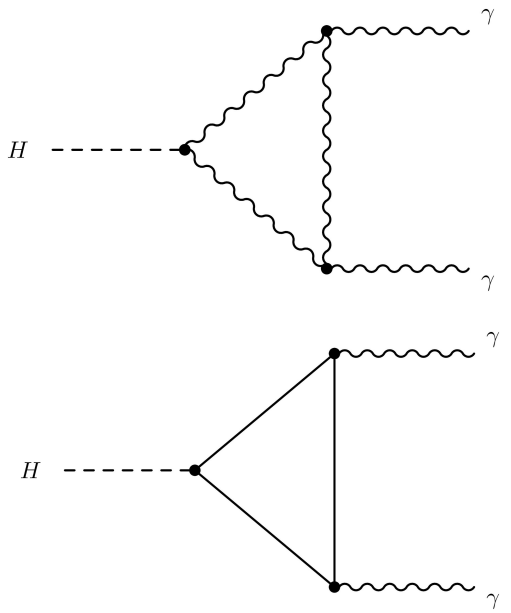
- The Berkeley ATLAS group covers almost all aspects of the ATLAS experiment, provides our graduate students a training program balanced between physics and detector instrumentation

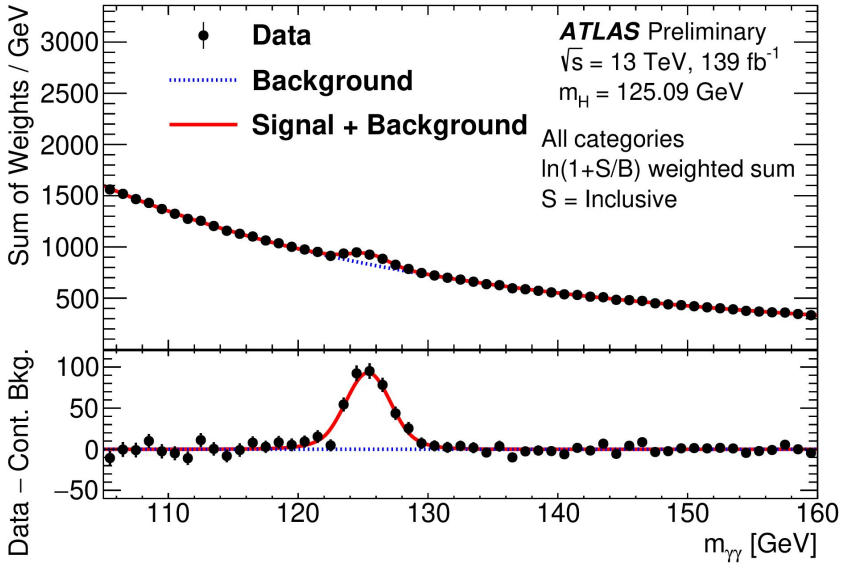
My presentation will be a continuation of physics and also include an overview detector upgrade

Measurement of the Higgs boson

We have long-standing leadership in one of the two channels that are most sensitive to the decay of the Higgs boson

- *$H \to \gamma\gamma$ (the other being $H \to 4$ leptons), Flagship measurement in ATLAS*
- *New physics appears in the loop and affects the rate*
- *It also serves as a simple tagger of the Higgs, allowing us to probe complex processes of Higgs boson production*

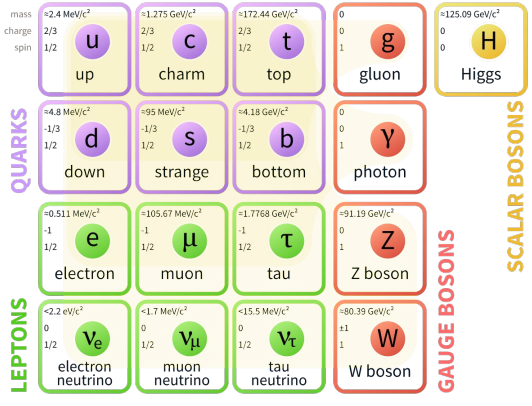


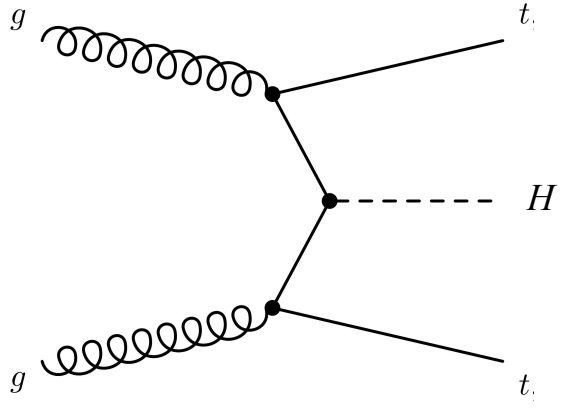


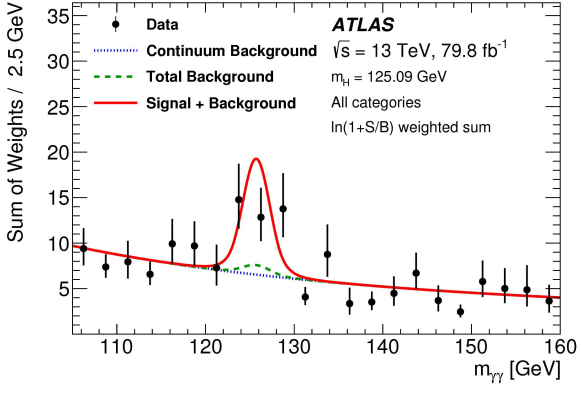
Observation of the ttH process

In 2018, the Berkeley group led the observation of the ttH process

- *The first direct evidence for the top-Higgs Yukawa interaction*
- *Top quark is the heaviest elementary particle*
- *High expectation that new physics shows up here*





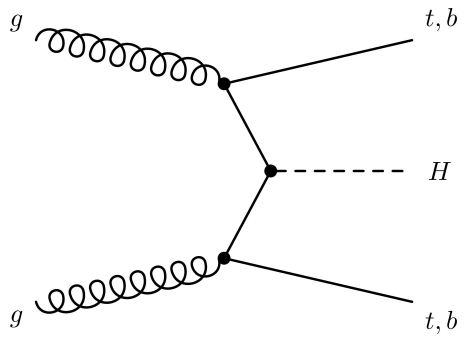


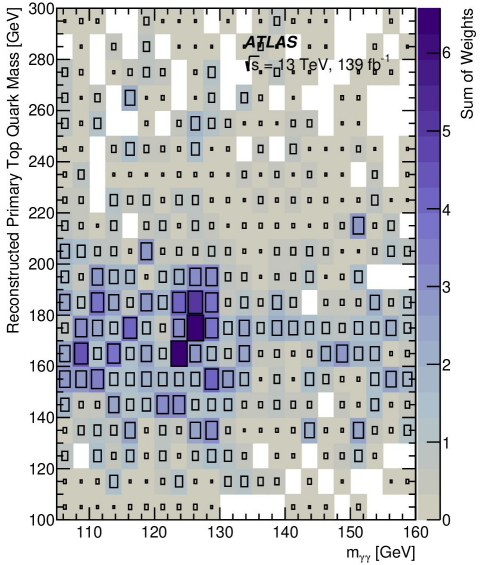
Former student Jennet Dickinson (PhD 20) made significant contribution to this measurement, great example how individual student's ingenuity and hard work can lead to game changer

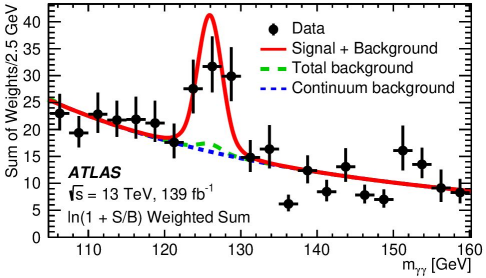
Top-Higgs Yukawa interaction

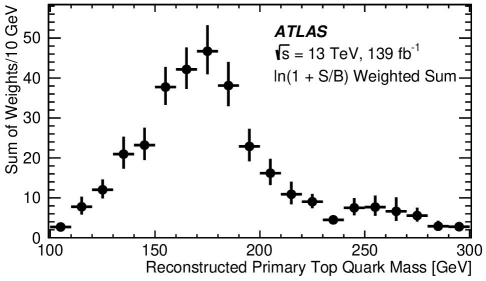
We followed up with a test of the CP property of the top-Higgs interaction

- *the first direct experimental test* ***Phys. Rev. Lett. 125 (2020) 061802***
- *PhD thesis for Jennet Dickinson*
- *exceptional authorship award for Ryan Roberts*





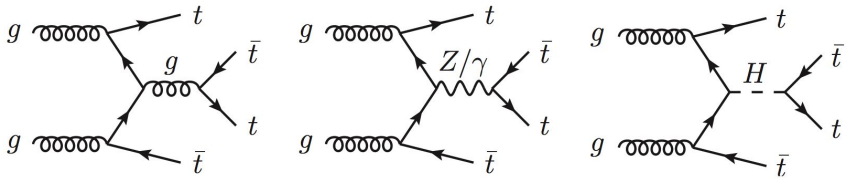


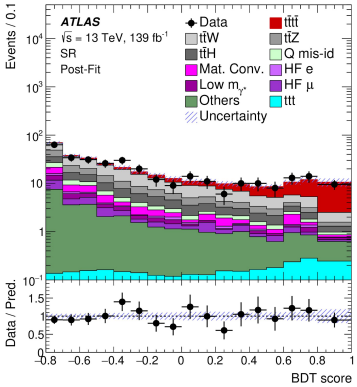


Four top quarks

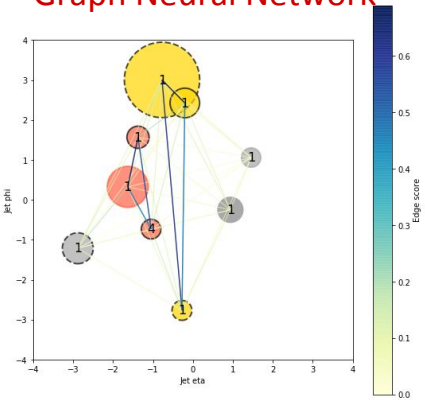
Measurement of the production of four top quarks

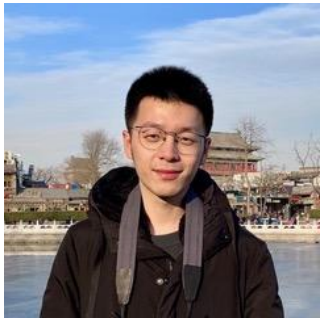
- *complementary approach to test the top-Higgs interaction*
- *current ATLAS result shows a 2σ level excess beyond the SM*
- *high multiplicity states require sophisticated machine learning analysis method*





Graph Neural Network



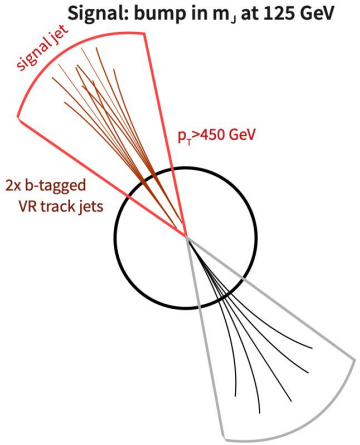


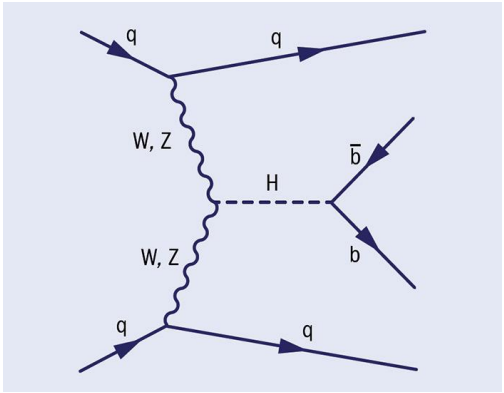
Grad - Roberts, PDs Ju and Han and undergrad: Allison Xu and Intern:Pamela Pajarillo

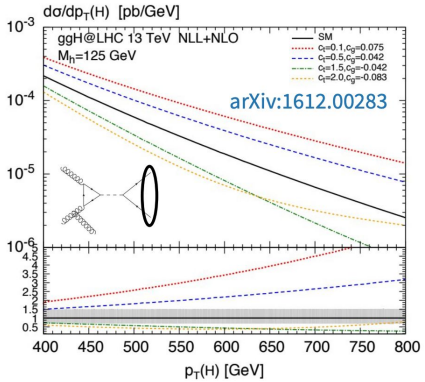
Measurement

This analysis measures the cross section of the Higgs boson at very momentum

- *A good example of measurement that was considered as impossible when LHC/ATLAS was conceived but is now possible due to development of new analysis technique*
- *Enhanced production rate may be indicative of the presence of new physics*







PD: Karol Krizka

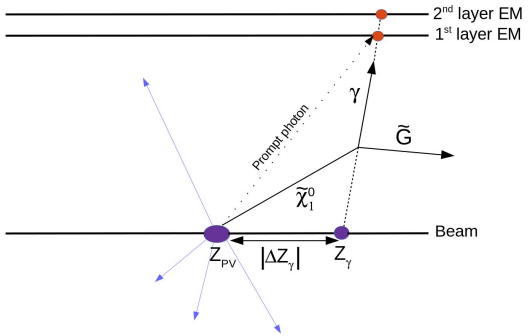
Search for delayed and non-pointing photons

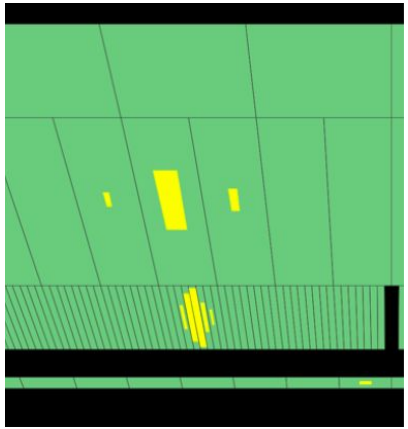
The majority of the seven million Higgs bosons produced at the LHC between 2015 and 2018 went undetected

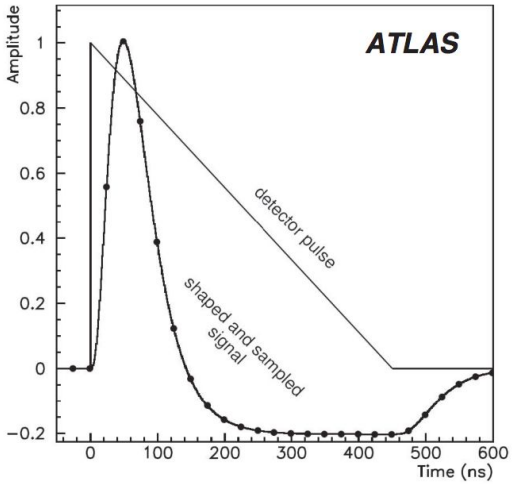
- *Large fraction can go to BSM final states*
- *Our search: Higgs boson decays to long-lived particles which in turn decay to photons and LSPs*

Example of data analysis using unique capabilities of our detector

- *non-pointing ⇒ multilayer calorimeter*
- *delayed ⇒ timing measured from pulse shape*

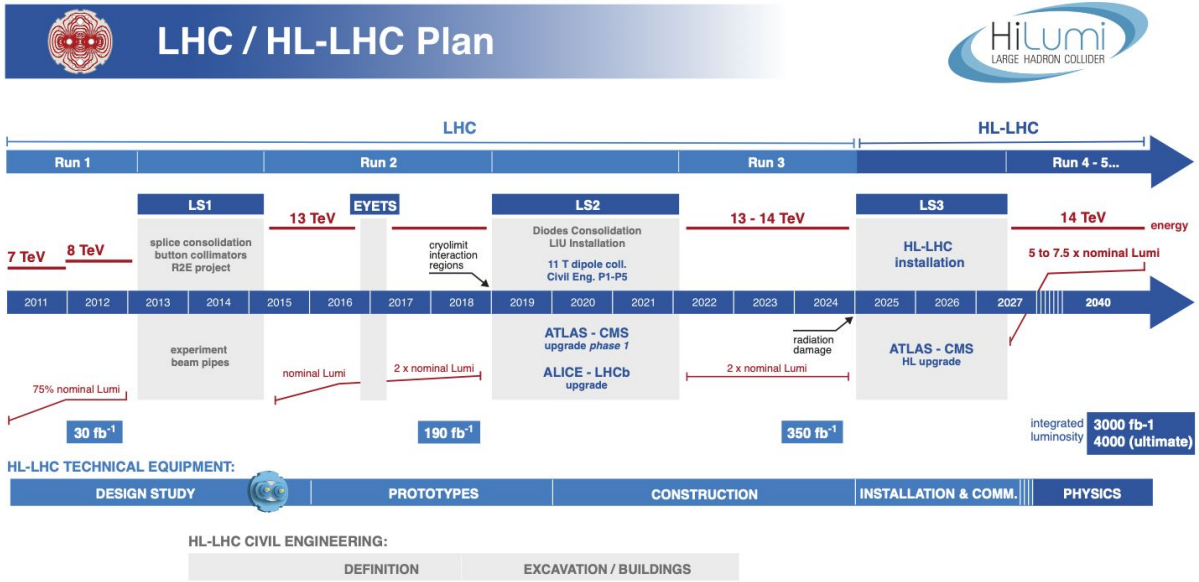






Grad Student: Sai Neha Santpur
Postdoc: Shuo Han
Undergrad: Earl Almazan

The High Luminosity LHC upgrade



- **The Large Hadron Collider will enter its Run-3 in 2022, delivering 350 fb^{-1}**
  - *~ 30 times more than Higgs discovery*
- **The High luminosity LHC upgrade takes between 2025 and 2027**
  - *upgrade of accelerator complex to enable much higher instantaneous luminosity*
  - *running until 2038, delivering a data set x 300 - 400 Higgs discovery*

Why we need to upgrade?

The High Luminosity LHC also requires significant detector upgrades

- *Detectors reach the end of their lifetimes*
- *Much higher event rates at the HL-LHC*
- *New technology*

Berkeley was a leader in the design of the original ATLAS tracker, and has been leading the R&D and construction for new tracker

- *the new inner tracker (ITk), that detects and measures charged particles, will be fully replaced*
- *the new tracker will be all-silicon, with a sensor area over 2000 ft^2*
- *we have major responsibilities to construct large portions of this new tracker*

The new silicon tracker ITk

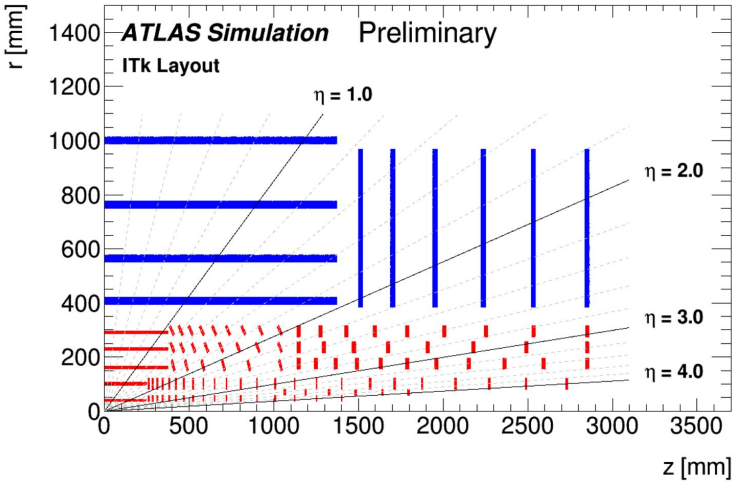
A silicon tracker is a position sensitive detector. It records the position where a charged particle traverses silicon sensor, by detecting ionization electrons. The tracker is immersed in a 2-Tesla magnetic field. Connecting the dots, we get the trajectory of the particle, and the momentum

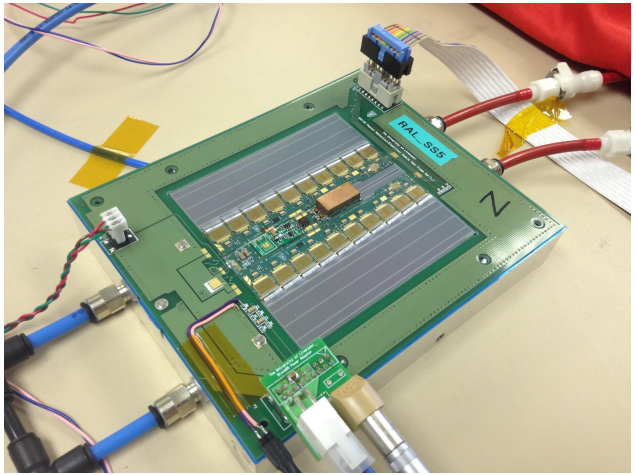
Pixel tracker

- *lower radii*
- *pixelated sensors (50 μm x 50 -150 μm)*
- *Huge number of readout channels*

Strip tracker

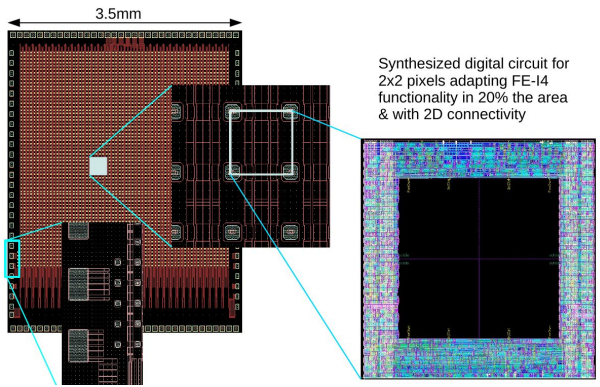
- *higher radii*
- *long strips (L 2.5 cm / 5 cm; W: 75 μm)*
- *Huge number of readout channels*





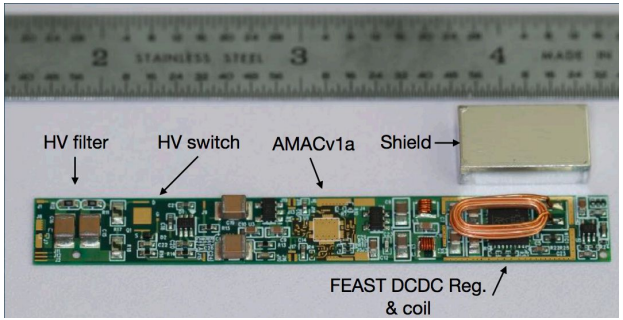
Recent examples of R&D

Design and testing of readout chips

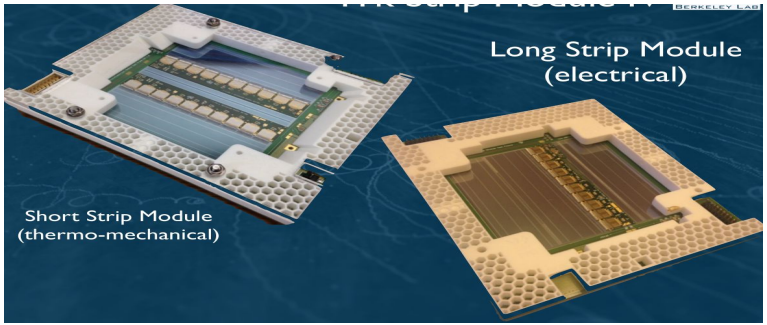


Synthesized digital circuit for 2x2 pixels adapting FE-I4 functionality in 20% the area & with 2D connectivity

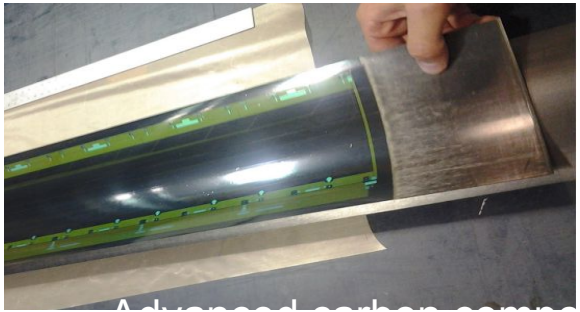
Design and testing of powerboard



R&D, production, and testing of modules



Design and testing of mechanical support structure



What comes next

- **Construction of new tracker: now → 2024**
  - *significant engineering challenges: electrical, mechanical, quality control*
  - *perfect opportunity to learn detector instrumentation*

- **Integration and commissioning at CERN 2024 → 2027**
  - *issues arising at system level*
  - *need to learn how to operate our detector*

- **The High Luminosity LHC: 2027 → 2038**
  - *detector operation at CERN*

Most of our graduate students spend a year or more working on detector project

Closing remark

The next few years will be an exciting period of time for graduate students working on the LHC experiments

- Our physics is exciting
- Increasingly large data set
- Emerging technologies: new detector, new readout and trigger capability, extensive application of AI/ML technologies
- Many of the analysis project has a measurement aspect and a search aspect; you always get something out of the work, and that will typically have a long lifetime

We train three-dimensional physicists that can provide leadership in physics analysis, detector R&D and operation for the future of particle physics